THE SEVEN SEALS OF SCIENCE

JOSEPH MAYER

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SCIENCE MOVES THE WORLD UPWARD TOWARD THE LIGHT

THE SEVEN SEALS OF SCIENCE

An account of the *unfoldment* of orderly *knowledge* & its *influence* on human *affairs*

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TO MY WIFE

whose intellectual companionship, wise counsel, helpful criticism, and constant assistance at every stage of the work have aided me immeasurably, this volume is affectionately dedicated

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PREFACE

The following pages aim to present popularly and yet accurately the essential features of scientific advance. So far as the limitations of space have permitted, they center upon the activities of the men who have done most to further orderly knowledge. Some names and many details, which from a circumscribed point of view might be considered important but which do not bulk large in the main forward movement, have been omitted, as have also certain controversial matters except where their inclusion was thought necessary to round out the story.

The central theme of the essay is that the sciences did not arise and could not have arisen simultaneously, that they form a well defined structure with mathematics at the bottom, that each later science built upon those that went before, that psychology is only now in process of becoming established, and that the social studies, if they are to be worthy of the name of science, must build upon the natural sciences and particularly upon geology, biology, and psychology.

In endeavoring to develop the major ramifications of this theme, the author is well aware of the immensity of the task and of his own shortcomings. Although the book represents the best part of twenty years of study in a number of directions, and although its plan was formulated nearly fifteen years ago, its publication at this time rather than some years hence must be credited to the growing impatience of the intelligent layman with those specialists who continue to regard their compartments of knowledge as water-tight and

self-sufficient. It has been well said, in this day of rapid multiplication of specialties, that as the doctor of philosophy has concentrated more and more on less and less, the college student and the layman have been forced to accept less and less of more and more. And the "less and less" has usually been presented in such technical language that only the initiated can make head or tail of it. For several years now an increasing number of people, students and men of affairs alike, have been demanding that the outstanding developments of science, shorn of technicalities and dry-as-dust details, be made available to them. It is hoped that this essay will accomplish something toward that end.

In order to assure as great an accuracy and completeness as possible, each chapter of the book has been criticized in manuscript by specialists in the fields covered. Grateful acknowledgment of helpful suggestions is here made to Professor W. F. Wyatt on the Greek period, Professor W. R. Ransom in mathematics, Professor David W. Cornelius in physics, Professor H. M. Chadwell in chemistry, Professor A. C. Lane in geology, Professor H. V. Neal and Dr. Rudolf Bennitt in biology, Professor R. C. Givler in psychology, and Professor Witt Bowden and Mr. David M. Cheney in history. Special thanks are due Professor Bowden and Mr. Cheney and also to Mr. Frank P. Sibley for their examination of the entire manuscript and for their searching criticisms.

Most of all, the author is indebted to that splendid group of Harvard teachers—notably George Herbert Palmer, William Wallace Fenn, George Foot Moore, Josiah Royce, Frank William Taussig, and Ephraim Emerton—who a decade and a half ago laid sure and deep the foundations of much of the critical thinking he has done since. The author, however, takes full responsibility for the develop-

ment of the material herein presented and for the conclusions reached.

Acknowledgment is also made of the kindness of several of the author's graduate students and friends for helpful suggestions and aid in the work of correcting manuscript and preparing an index, especially Mr. D. G. Taylor, Mr. W. R. Leonard, and Miss Irene A. Rachdorf, and of Dr. George Sarton, Dr. Frederick H. Brasch, Dr. Harlow Shapley, the "Yale Alumni Weekly," the American Museum of Natural History, and the "New York Times," for the loan of a number of the portraits and photographs and the original Cesare drawings. It should be added that two chapters—the fourth and the fifth—have appeared as articles in the "Scientific Monthly" and in "Science Progress."

It is hoped that this essay will be of interest to the general reader, of assistance to students of science, and not lacking in helpfulness to those specialists who desire to maintain a broad perspective while they pursue with increasing detail their individual fields of investigation.

JOSEPH MAYER.

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CHAPTER I

THE BOOK OF NATURE VERSUS THE BOOK OF MAN

§ 1

THE outstanding feature of the age in which we live is the achievement of physical science. Advances in physics and chemistry have revolutionized our ways of living and of making a living. In a relatively brief period of time, the steamship, railroad, automobile, X-ray, electric light, telegraph, telephone, synthetic chemical products, and the mass production of watches, cameras, innumerable electrical appliances, and a thousand and one other recently created necessities and comforts have brought within the reach of the humblest citizen commodities that but a few years back could be enjoyed by the very rich only, or were not available at all. We are still marveling at the wonders of the airship and the radio, and no longer read with skepticism about "death rays," life on Mars, or the transmutation of base metals into gold. Everything seems possible in this era of physical advance, nor does any reason appear why such advance should not continue.

Material progress has gone forward beyond our wildest dreams. At the same time, social development, where achieved at all, has made headway at a snail's pace. While we have been harnessing physical forces, political, economic,

legal, and ethical questions have grown enormously more complex, and authorities are at loggerheads regarding solutions. Social problems, it is true, have been complicated in some respects by the advances in the material realm, as, for example, poison gas and submarines have added to the horrors of war; but such complications simply serve to emphasize the pressing need for adequate sociological solutions.

The entire world is weltering in a muddle of perplexing social difficulties. The recent war has raised many new problems, and it is extremely doubtful whether it has solved any. Political corruption in high places; the cumulatively aggravated struggle between labor and capital and the threat of revolution; the alarming post-war increase in insanity, hold-ups, murders, and suicides; the disrespect for law apparent on every hand; profiteering; the Far-Eastern question; increasing religious intolerance and fanaticism—such unsolved problems give us cause to wonder at man's seeming impotence in social affairs when he has been so eminently successful in the material realm.

Several recent writers have stimulated thought in this connection. In "The New Decalogue of Science," Albert Edward Wiggam gives us some warnings which, together with John Langdon-Davies's counter-arguments in "The New Age of Faith," are well worth reading and pondering. Wiggam pictures the advanced races of the world as going backward, with little hope of replenishing good stock once bred out of the social structure. He points to other equally alarming disasters awaiting humanity just around the corner, and pleads with the statesman to apply the lessons of biology to the solution of social problems before it is too late. Langdon-Davies is just as much concerned about the matter but looks to environmental changes, rather than to controlled heredity, for a solution.

Even more stimulating is James Harvey Robinson's essay on "The Mind in the Making," wherein he urges the necessity of applying the findings of psychology to social reform. He says:

When we compare the discussions in the United States Senate in regard to the League of Nations, with the consideration of a broken-down car in a roadside garage, the contrast is shocking. The rural mechanic thinks scientifically; his only aim is to avail himself of his knowledge of the nature and workings of the car, with a view to making it run once more. The Senator, on the other hand, appears too often to have little idea of the nature and workings of nations, and he relies on rhetoric and appeals to vague fears and hopes or mere partisan animosity. The scientists have been busy for a century in revolutionizing the practical relations of nations. The ocean is no longer a barrier, as it was in Washington's day, but to all intents and purposes a smooth avenue closely connecting, rather than safely separating, the eastern and western continents. The Senator will nevertheless unblushingly appeal to policies of a century back, suitable, mayhap, in their day, but now become a warning rather than a guide. The garage man, on the contrary, takes his mechanism as he finds it, and does not allow any mystic respect for the earlier forms of the gas engine to interfere with the needed adjustments.

The garage man, moreover, proceeds with the assurance that he *can solve* the mechanical problems before him. The social engineer cannot go ahead with any such confidence. If he is candid, he will admit that no trustworthy procedure for solving social difficulties has yet been devised.

An astonishing contrast, therefore, confronts us as between the physical sciences and the social studies. In the one field, we proceed with aplomb and certainty and have made tremendous progress. In the other, we are almost hopelessly confused, and it is even questionable whether any real advance is being brought about. Why does this amazing situation exist? Why has progress been so rapid

in the material realm and almost at a standstill in the social?

§ 2

Many partial answers to these questions are being attempted, but most of them are quite beside the real issue. One answer, however, touches the heart of the difficulty, and that pertains to the essentially different way in which the material universe, on the one hand, and the social structure, on the other, have been built up.

Nature, in constructing the former, has worked in ways we call "scientific"; and it has been man's discovery of those ways which has enabled him to advance so fast materially. On the other hand, *man* built the latter, not scientifically, but in the main haphazardly. In shaping his politics, economics, jurisprudence, and ethics, he groped in ignorance and misconception. In fact, this could not have been otherwise, since he was forced to begin building his society long before he knew anything about natural law. It is as if Nature in the dim distant long ago wrote a book, which we now call the natural sciences, and as if Man very much later began the writing of another book, still unfinished, the book of human society. Man's Book, to be understandable and scientific, should follow precisely the lines laid down by Nature's Book, but it as yet does not. It has been written largely as a child might write it, without understanding and knowledge, and its various erasures and additions have occurred chiefly as war or famine or social upheaval has guided the pen. Only as man applies the lessons of the Book of Nature to the thoroughgoing revision of his Book of Society can he hope for intelligent and rapid social progress.

The Book of Nature, however, has not been easy to open and read, for man had first to learn what scientific thinking

meant before he could begin to unseal and turn the pages. He discovered the significance of natural law and its ramifications after many centuries of laborious effort. In addition, suffering and martyrdom have been the lot of those who have led in the search for orderly knowledge. Socrates, Roger Bacon, Bruno, Galileo, and a host of others paid the price of scientific advance in daring to set their fearless thought against the superstition and prejudice of the periods in which they lived.

In Revelation we are told that in the world's infancy seven great seals bound the Book of Truth and that no one then on earth or in heaven or under the earth could open and read the book. This simile fits admirably into our conception of the original condition of the Book of Nature. Only now is man loosening the last of the "seven seals"—the seals of mathematics, astronomy, physics, chemistry, geology, biology, and psychology. His struggle to break them and acquire the habit of scientific thinking marks one of the most commanding achievements in his history.

§ 3

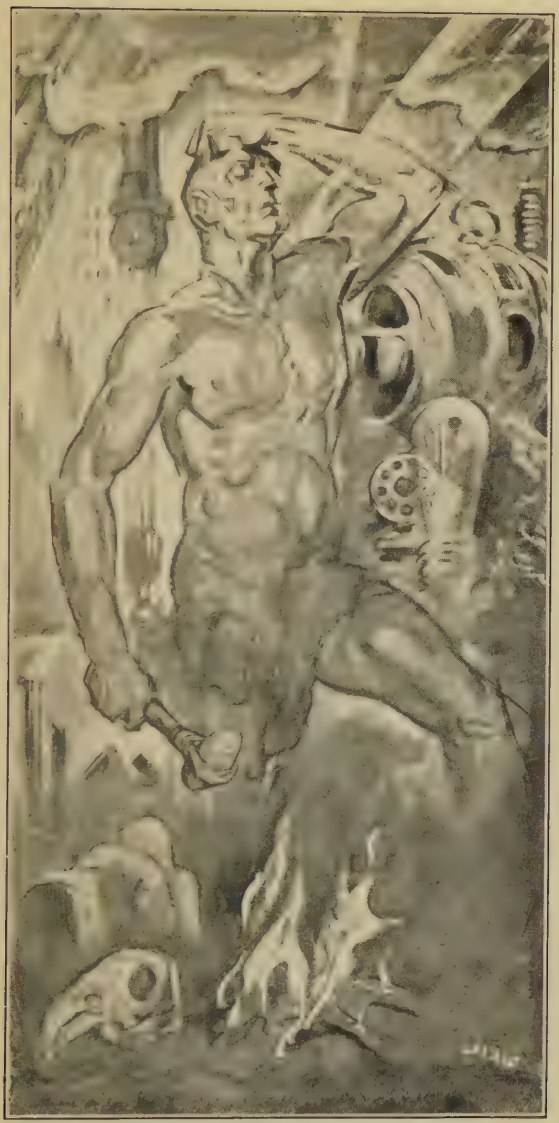
In the childhood of *Homo sapiens,* some fifteen thousand years ago, primitive man, knowing nothing of nature's forces, was dominated by fear and uncertainty. Chaos and mystery surrounded him. Nature appeared capricious and vengeful. Day-to-day occurrences looked strange and unrelated, and he made no distinction between dream fancies and waking experiences. Not only were myth and fact inextricably confused in his thinking, but no method existed for weeding out the true from the false in passing on tribal knowledge from generation to generation.

In those days, most of the actual happenings of nature, such as thunder and lightning, the howling of the winds,

pestilence, famine, suffering, and death, very naturally provoked fear. These appeared to be expressions of the wrath of the gods or of evil spirits, which as a consequence had to be propitiated with sacrificial offerings or formulas of incantation and magic. The sunshine, the warm rain, and similar occurrences inspired confidence and thankfulness; but at the beginning beneficial happenings seemed few and far between.

It did not occur to primitive man for thousands of years that nature's ways could be understood. There is a widespread regularity in the universe, but this was not known until comparatively recent centuries. That the moon and stars, for example, move in unvarying courses, dawned in very slow stages upon the comprehension of man. Evidences of natural law made little impression so long as savage man battled for existence with wild beasts and men and with the seemingly fitful and fortuitous circumstances he encountered from day to day. Only as relative security was assured, did fear and uncertainty become somewhat mitigated and did man take a more courageous and questioning attitude toward the universe.

Among the less obvious periodic events of which man finally began to take cognizance, were those having to do with the seasons. It was an important step forward in man's conquest over nature when he discovered that spring, summer, autumn, and winter follow at regular intervals and in regular succession. Before this knowledge came, any routine planting or harvesting of crops was impossible. The only reliable way of predicting seasonal changes in early times (with calendars and clocks unheard of and the conceptions of year and month and week still to be worked out) was by a continuous watching of the starry heavens. It is the yearly movement of the earth about the sun (now near, now farther away) and the inclination of its axis



Courtesy of the New York Times

MAN'S STRUGGLE TO BREAK THE SEALS OF SCIENCE

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which produce the seasons. The sky was and is the only final guide to a number of periodic changes affecting man's lot, and gradually this truth came to be appreciated.

As settled agricultural populations developed on the Nile, in Mesopotamia, India, and in China, a goodly amount of rule-of-thumb knowledge of the heavens came to be accumulated as a guide to man, beginning around 5000 B.C. and continuing for several thousand years. With the establishment of Egypt and Babylon, astronomical knowledge in the then Western World took on a scope wide enough to make possible the prediction of eclipses of the sun and moon, an achievement which implied the recording of observations over long periods of time, for eclipses occur at rare intervals only. The Egyptians arranged their mighty pyramids with due regard to astronomical events, and the Babylonians noticed the "wanderers" among the "fixed" stars of the heavens and accordingly called them the equivalent of our word "planets," which means "wanderers."

At the same time that these early civilizations were teaching man what to expect of nature in many circumstances, they were providing him with some security against calamity. But in the three or four thousand years that the Egyptians and the Babylonian-Sumerians had been establishing themselves, they had developed an elaborate idol worship to which they credited all their good fortune. They continued to regard nature as on the whole wilful and capricious and to people the heavens with many gods whose favor must be gained for the assurance of material blessings and for the prevention of disaster. Their rule-of-thumb knowledge was still thoroughly mixed up with ceremonies of propitiation, and fear and superstition continued to dominate their thinking.

Then it was that, to the land of the Ægean in the northeastern region of the Mediterranean Sea, where the gifts

of nature abounded and where another ancient culture (Cretan, or Minoan) had already developed, there came around 1500 B.C. the tribes of invading Greeks which were destined to found a new civilization. The siege of Troy, so picturesquely described by Homer, may be taken to represent the last stand of the earlier inhabitants against the invaders. The influence upon the Greeks of the older Ægean and Cretan civilizations, however, was considerable, as is only now coming to be clearly appreciated.

Here, in an earthly paradise, the Ionian Greeks for many centuries found "wholesome release from the shell-shock of catastrophic environment." More important than this, fear failed to retain a place in their views of the universe as it had with the Egyptians and the Babylonians. Their gods became friends and counselors rather than despotic overlords. The Ionians found leisure to look about and ask themselves questions regarding natural phenomena. And from their loins sprang a group of fearless thinkers, whose penetrating insight into nature's secrets paved the way for science and remained unsurpassed till modern times.

These ancient thinkers asked the why of things insistently. They purged speculative thought of the groveling fear that had theretofore dominated it. They insisted that nature is orderly and can be understood. And in the end they formulated a new method for interpreting her ways. This method we now call scientific.

To-day the difference between the speculative and the scientific methods is well defined. It is aptly illustrated by the story of the manner in which two men who had never seen a camel went about determining what this strange creature is like. One took a trip to Egypt and made an observational study of it in its native habitat. The other, so the story goes, locked himself in his study and proceeded to evolve a camel out of his inner consciousness! The specu-

EUROPE
BLACK SEA
MACEDONIA
ITALY
ROME
STAGIRA
GREECE
TROY
IONIA
AEGEAN SEA
ASIA MINOR
MT. MYCALE
MILETUS
SYRACUSE
CRETE
CYPRUS
MEDITERRANEAN SEA
CASPIAN SEA
ASSYRIA
TIGRIS
EUPHRATES
MESOPOTAMIA
PHOENICIA
BABYLON
BABYLONIA
ASIA
CHINA
INDUS
PERSIA
NORTH AFRICA
ALEXANDRIA
CAIRO
EGYPT
NILE
RED SEA
ARABIA
PERSIAN GULF
INDIA
AFRICA
INDIAN OCEAN
THE ANCIENT WORLD
THERMOPYLAE
GREECE
TROY
AEGEAN SEA
IONIA
MARATHON
SAMOS
MT. MYCALE
PLATAEA
ATHENS
MILETUS
SALAMIS
MINOA
CRETE

lative individual pays no attention to observational data. The scientific investigator observes and records the facts of nature, analyzes them critically, and if necessary repeats the observations time and again before a conclusion is reached.

Now, each of these modes of procedure has its place. Each, in its own way, endeavors to explain the world and its mysteries. To say that "evolving camels," building air-castles, day-dreaming, speculation, are all made of the same stuff is not to disparage the value of speculation, though the foregoing illustration indicates that it can be misapplied. There are many questions, some of them most intimate and insistent ones, to which science as yet affords no answer, and regarding which speculative conjectures are the only recourse. Questions about birth and death, about the reasonable assumption that there is some intelligent power or deity guiding human affairs, about man's relationship to this power or deity—these and similar questions have troubled man from earliest times. Science has solved many lesser problems, but the outstanding mysteries remain unexplained. Conjecture logically enters where science leaves off. It uses the intuition and the imagination to fill the gaps in our knowledge.

Science proceeds by slow and painstaking observation and experiment to build precedent on precedent, and as it extends the confines of knowledge speculation should retreat. This principle is well recognized to-day, even though in practice scientific conclusions and speculative assumptions are still often confused. But before the days of the Greeks the scientific approach was absolutely non-existent. Thinking was either speculative or by rule of thumb, and was fettered by fear and superstition.

The first task of the Greek thinkers, long before they

discovered the scientific approach, was to purge conjecture of this superstitious fear. In doing that they created philosophy as a system of orderly thought. The regularity of physical and astronomical phenomena was observed by them to be at variance with the assumed capriciousness of the Hellenic gods, and this led to the conception that above these supposed whims stands an immutable Justice, a divine Law, a supreme Intelligence. In man's thinking systematic procedure began to take precedence over fickleness and chance. These early philosophers relegated the ancient gods to the realm of fables and attempted to explain the mysteries of the universe in terms of principles and causes, even though they met severe opposition in advancing the new ideas. The struggle between the orthodox Greeks and the "heretical" philosophers was intense and at times led to persecution and martyrdom.

It was in the process of establishing Greek philosophy that these pioneers in fearless thinking came face to face with their greatest problem, the one out of which they ultimately evolved the scientific method. They had transformed superstitious fantasy into orderly reasoning, but as yet they had found no assured way of building up a reliable body of truth. Their philosophies were still in the main conjectural, and many divergent ones soon had the field. Outstanding thinkers were contending that the senses are deceptive and that all truth comes from within, from the still small voice of conscience and intuition through which it was thought the contents of the Book of Nature are revealed directly to man. The chief spokesmen for this view were Socrates and his pupil Plato. Yet how was one to choose between the many contradictory philosophies? One man's guess seemed just as good as another's. It was at this point that Aristotle took up the challenge of the Pla-

tonists and insisted that it is not by intuition at all but only by a deliberate observation of nature that the true can be separated from the false in our thinking.

It is not to be thought that there were no scientific advances in ancient Greece before the days of Aristotle. Plato himself, despite the emphasis on intuition in his writings, was a keen observer, and so were other Greeks beginning as early as two centuries before his day, as we shall have occasion to observe in the next chapter. In fact, the Egyptians and Babylonians (as well as the Chinese) had made important astronomical and other scientific observations, even though they exhibited little of the spirit of free inquiry and discovered certain facts about nature more or less accidentally, immediately weaving them into the mystic fantasies of their superstitions. The point is that no one had analyzed the significance of the observational method before Aristotle. His epoch-making contribution was to give conscious emphasis to it as the *only* method for building up a verifiable body of facts—facts on which every one could agree. For the first time, so far as is known, a deliberate dependence was placed upon the evidence of the senses. Aristotle recognized that sense impressions are sometimes deceptive; hence he insisted on *repeated* observation. He recognized also that the reasoning processes are often undependable and devised the science of logic to guard against fallacious deductions. Thus was formulated a new method in the search for truth. The way had finally been found to break the Seals of Science.

In retrospect, this discovery of the scientific method stands out clearly as one of the most important achievements of all time. To the ancient Greeks, however, it was merely one of the many ways in which they groped for the truth, and there was little clear apprehension then as to which was the best way. Only a very few in those days

were destined to catch the scientific spirit, and meanwhile philosophic conjecture continued unabated. The real wonder is that any of the ancients followed this new way of thinking as closely as they did. Their greatest error, if error we must call it, lay in not realizing that there was much to be learned about natural phenomena and that there were certain departments of scientific knowledge which had to be mastered before others could be understood.

The ancients did not appreciate, in other words, that the Seals of Science had to be broken in a more or less definite order or sequence, which appreciation in fact has come only in our own day. One cannot hope to gain much fundamental knowledge about any science until those preceding it in the sequence have been somewhat established and mastered. For every science except the first is dependent upon those that go before; the series, as we shall discover for ourselves, starting with mathematics and extending through astronomy, physics, chemistry, geology, biology, and psychology.

The Greek thinkers very naturally knew nothing of this sequence. They attempted to master all departments of knowledge at once; and although they failed in this larger endeavor, it is to their eternal credit that they succeeded so well with mathematics, the foundations they established coming down to us practically unchanged. They made some headway, also, with astronomy, but here as in physics they were hampered by a false view of the universe and its forces. Their supreme achievements lay in bequeathing the scientific method and the science of mathematics to posterity. Without this mode of inquiry and the insight which mathematics affords, astronomy, physics, and chemistry could not later have been mastered; and, in turn, without the development of these sciences, geology, biology, and psychology could not now be understood.

§ 4

It will be illuminating to trace the difficulties man encountered in his struggle to break the Seals of Science, for such are the difficulties he will undoubtedly continue to face if he would revise the Book of Society along scientific lines. The fear, superstition, and ignorance he has grappled with and is still grappling with in the field of natural science face him with renewed and even more bitter antagonism as he turns to social problems. Biology and psychology continue to struggle against the forces of darkness and ignorance. In many places it is still somewhat hazardous to assert a belief in evolution. And what the situation will be, when social problems come to be attacked scientifically, can only be surmised. The hope of mankind, at any rate, is that fearless thinkers will continue to come and labor, even though their gifts are heaped upon a thankless and misunderstanding contemporary world. The only consoling thought in this connection is that succeeding generations will undoubtedly build monuments to the martyrs their fathers have stoned. Such, at least, is part of the evidence which the history of scientific advance presents.

There is another value in recounting man's achievements in natural science. The outstanding lessons of the now almost completely unsealed Book of Nature must become the common property of mankind before an adequate revision of the Book of Society can be undertaken. Few people as yet appreciate even in broad outline what the Book of Nature reveals. Wiggam, Langdon-Davies, Robinson, and others point out how little the revelations of modern biology and psychology have penetrated into our common intellectual and social heritage. And the revelations of psychology and biology are but a part of the knowledge that must be encompassed for the task ahead. In addition,

there are the developments in geology, chemistry, physics, astronomy, and mathematics, which, though better understood, are still to be made the foundations of the everyday thinking of the man on the street.

The present recrudescence of fantastic beliefs, and the activity of self-styled fundamentalists in endeavoring to belittle scientific achievements, focus attention upon the crying need for bringing the general meaning of science home to the people. Modern science itself has contributed to the present confusion of thought by becoming specialized into many almost water-tight compartments. Scientists holding strictly modern views in their own and closely related fields are often woefully ignorant of other fields, and this is especially true when social problems are approached.

The time has come for presenting the meaning of scientific advance as a whole. A bird's-eye view of the sciences, a knowledge of the sequence of their development, and an appreciation of their relation to social problems should be the common possession of all thinking people. To contribute in some small measure to this general enlightenment is the purpose of the present essay.

CHAPTER II

THE GOLDEN AGE OF GREEK LEARNING

§ 1

WHAT has been aptly called the golden age of Greek learning has a much wider significance than the reign of Pericles to which it is often exclusively applied. From beginning to end, it lasted nearly a thousand years, extending over more than twice the interval from the discovery of America in 1492 to the present day. It began about the seventh century before the Christian era and ended with the decay of the Roman Empire.

During this period Greece passed through many political vicissitudes. She lost her freedom in 338 B.C. when the king of Macedonia, who ruled over an adjacent people related to the Greeks, brought the city-states under subjection. But the Macedonian was wholly friendly to Greek learning, and in fact had his son, the future Alexander the Great, trained at the hands of the best of the Athenian scholars, among them Aristotle, one of his own countrymen although a Greek by adoption. When Alexander, around 330 B.C., carried his memorable military campaign into Central Asia and Northern Africa, he spread the Hellenic culture to these lands. He likewise gave it renewed impetus in the establishment of Alexandria, Egypt, where his successor Ptolemy founded a great center of learning. Here Greek science continued to flourish long after the light of scholarly activity flickered and went out in Western Europe.

§ 2

Conspicuous among those who first turned the attention of the Ionian Greeks away from superstitious fantasies to fearless inquiry was Thales, born about 640 B.C. in the Greek colony of Miletus on the coast of what is now Asia Minor. Thales was a Phenician by descent and was at first occupied as an engineer and merchant. He made numerous trips to Egypt, where he spent considerable time studying the native methods of observing and recording astronomical events. While there he also investigated the methods of geometric triangulation used to reëstablish landmarks periodically wiped out in the overflow of the river Nile. Finally he settled down in Miletus and introduced his fellow-Ionians to a serious study of the heavens and the properties of geometrical figures. His relationship to a seafaring and mercantile people (the Phenicians), who had already developed a system of numbers for reckoning in their commercial dealings, gave him a very natural advantage in mathematical reasoning. He developed several important theorems in geometry, and is said to have calculated the height of an Egyptian pyramid by measuring its shadow and making use of the principle of similar triangles.

In astronomy, Thales began a series of searching inquiries based upon the crude materials furnished by the Egyptians and the Babylonians. It was not known at that time, for example, that the moon, interposing itself between the sun and the earth, causes the solar eclipse. Thales worked this out, and concluded from his results that the moon is a dark body, shining by reflected sunlight. Going further, he explained the various phases of the moon (that is, new, first quarter, full, and last quarter), which phenomena had previously been complete mysteries. Thales

successfully predicted the eclipse of May 28, 585 B.C., and taught that the year contains 365 days.

Many astronomical happenings, which are commonplaces to us, were mysteries at that time. The earth was considered to be a flat surface, immovable, and completely surrounded by water; the sun was regarded as being driven in a chariot across the skies each day from east to west.

Courtesy of Ginn and Company. From "A History of the World" by James Henry Breasted

MAP OF THE WORLD BY HECATÆUS (517 B.C.)

Soon after Thales and his followers put forth the results of their researches, however, new conceptions arose. Many bold assumptions were made regarding the structure of the universe, most of which were naturally wrong because of the limitations of knowledge. The surprising thing is that some of them were so nearly right.

It is still popularly believed that Columbus was the first man to regard the earth as a sphere. As a matter of fact the early Ionian thinkers discovered this truth many centuries earlier. It was observed by the followers of Thales, in traveling long distances (as from Greece to Egypt), that southern constellations, which in their native land seemed fixed except for the apparent daily rotation of the heavens about the earth, gradually got higher and higher in the sky; from which they concluded that they were traveling

over a curved surface. By utilizing this observation and the newly created principles of geometry, they actually calculated the earth's diameter with some approach to accuracy. The conception of a spherical earth came to be held by most of the eminent Greek thinkers soon after the days of Thales, although they differed in their ideas as to whether the earth is fixed or in motion, both with regard to its own axis and with respect to the sun.

Pythagoras, the Sage of Samos, born about 580 B.C., was the most renowned follower of Thales, and his logical successor. Like Thales he traveled extensively. Much of his life is shrouded in mystery, but it is now fairly well established that among other things he assimilated considerable Phenician, Egyptian, and Babylonian learning, and in addition imbibed the culture of India, returning not to his home city, which was situated close to Miletus, but to one of the Greek colonies in Southern Italy, where he established a secret brotherhood pledged to social reform and developed a school of learning. Pythagoras mastered all known fields of knowledge, including geometry, astronomy, music, and medicine. He and his followers, in some respects at least, set the high-water mark of Greek scientific advance. The Pythagoreans became a powerful influence against the skepticism and materialism which were developing and indirectly brought about the spiritual reaction of Socrates and Plato.

In mathematics, most of us remember Pythagoras by the theorem he is said to have deduced, with respect to a right-angle triangle, that the square of the hypotenuse is equal to the sum of the squares of the legs or other two sides. Pythagoras supplemented the Thalean study of lines, triangles, and other geometrical figures by an extensive investigation of the properties of the circle and the sphere, and successfully applied the results to additional discoveries

in astronomy. His followers placed geometry upon a scientific basis, by adding, to the properties already developed, formulæ for ascertaining the areas of the triangle, square, parallelogram, and other polygons, and the volumes of most of the regular solid figures.

Pythagoras began, also, a geometrical study of the properties of numbers. He it was who first distinguished between odd and even numbers—a distinction now taken for granted. He noticed that certain numbers, starting with unity and taking every other one, form a group all to themselves, since they have peculiar properties as a class; so he called them "odd" numbers. Some of these properties are well known to us; others are not. For example, the sum of any consecutive series of odd numbers starting with unity always forms a perfect square. Thus:

$$1+3=4, \text{ or } 2^2$$
$$1+3+5=9, \text{ or } 3^2$$
$$1+3+5+7=16, \text{ or } 4^2$$

and so on. These results Pythagoras demonstrated pictorially by using dots and building up squares as follows:

How one plus three plus five plus seven dots form successive squares is thus readily apparent. The numbers which do not belong to this "odd" group, Pythagoras called "even"—a classification which has been handed down to us unchanged.

Pythagoras demonstrated a close relationship between music and mathematics, by using odd and even numbers to produce octaves and chords, and the principles he deduced

are used to this day as basic in the study of harmony. Despite the clumsy arithmetical notation of the Greeks (quite similar to the Roman numerals still inscribed on public buildings to-day), the later Pythagoreans worked out arithmetical progressions; analyzed number series of various kinds; invented the idea of ratio and proportion; discovered what they called irrational numbers, such as the square root of two ($\sqrt{2}$); and discerned many other important number properties.

Most of these advances served later as short-cut methods for further scientific investigation. When a scientist says, for example, that one thing is to a second as a third is to a fourth, he is employing the short-cut language of ratio and proportion. To use a concrete illustration, we say two is to four as nine is to eighteen $\left(2:4::9:18, \text{or} \frac{2}{4}=\frac{9}{18}\right)$. If one of the elements of the proportion is unknown and is sought, as $x:4::9:18$ $\left(\frac{x}{4}=\frac{9}{18}\right)$, we can calculate its value by the elementary mathematical maneuver of cross-multiplying, that is, $18x=36$, or $x=2$. Many physical relationships, such as between time and velocity, can be conveniently expressed in the form of ratios and proportions. With respect to circles, it was determined by later Greeks that the ratio of any circumference (c_1) to its diameter (d_1) equals the ratio of any other circumference (c_2) to its diameter (d_2)—meaning:

$$c_1 : d_1 :: c_2 : d_2 \quad \text{or} \quad \frac{c_1}{d_1}=\frac{c_2}{d_2}$$

This generalization regarding the circle illustrates another mathematical idea which is fundamental in scientific reasoning to-day. To say that $c_1 : d_1 :: c_2 : d_2$ is to state the principle that the relationship of diameter to circumference

is an unvarying ratio, that is, a constant. Science is eternally searching for the uniform ratios, the invariants of nature. Where it is discovered that an invariable relationship exists, but the precise value of the constant is unknown, the symbol k is now used to designate it (the precise symbols employed in these pages were not used by the Greeks). Thus, with respect to the circle, the foregoing statement that the ratio of diameter to circumference is constant becomes $\frac{c}{d} = k$.

A great Alexandrian Greek mathematician later calculated this invariant to be equal to 3.1416—, otherwise known as *pi* (π).

Such examples of mathematical symbolism and its use give one a preliminary insight into the value and meaning of mathematics. This science furnishes the tools of precise and short-cut reasoning without which the seeker after truth could never get beyond the most elementary stages of fact gathering. It is not enough in scientific investigation to make observations of natural phenomena. One must also be in a position to interpret accurately the meaning of the facts adduced. Mathematics is indispensable for such interpretation. As the first of the sciences, it embraces the most general aspects of natural phenomena, their number and space relationships.

In astronomy, the achievements of the Pythagoreans were equally as notable as their contributions to mathematics, even though their theories were infused with considerable speculative mysticism and failed of acceptance by the great Aristotle. Pythagoras and his followers not only pictured the earth as a sphere but actually put forth the hypothesis that the earth moves through space and turns on its axis every twenty-four hours rather than the whole universe revolving around it. Aristarchus, one of the later Pythagoreans, went even further and virtually

anticipated the modern theory of planetary motion. Utilizing geometrical principles, he attempted to calculate the distances of the sun and moon from the earth. He succeeded in part, thus giving a first intimation of the enormous size of the sun. The later Pythagorean view of the universe was thoroughly modern and had it prevailed would have put astronomical knowledge ahead some two thousand years.

But the time was apparently not then ripe for a cosmography or theory of the universe which runs counter to the obvious. The evidence of the senses has it that the sun and stars travel across the heavens every twenty-four hours and that the earth is fixed and immovable. With this common-sense assumption as a basis, other Greek thinkers worked out a series of circles and spheres to represent the motions of the heavenly bodies around a fixed earth. It seems that Plato, a century and a half after Pythagoras, was among the first to suggest such a system, though he did not complete it, a task which was left to two of his followers (Eudoxus and Callippus) who used thirty-three spheres for the purpose. "They imagined the sun, moon, and planets to be fixed in spheres, which revolve within other spheres, all in turn revolving about the earth." Aristotle later carefully examined both the Platonic and the Pythagorean cosmographies and decided in favor of the spheres and circles and a fixed earth. The burden of proof against common-sense impressions was still too great to be successfully met, nor had the Pythagoreans attempted to work out their astronomical theories with any precise mathematical detail.

Though we shall presently consider the contributions of Plato and Aristotle more at length, it is well to bring in here another erroneous hypothesis they held. This covered their ideas about the phenomena of physics and is im-

portant, though fanciful to us, since it dominated scientific thinking until Galileo's day around 1600 A.D. Plato and Aristotle, following earlier Greek thinkers, placed a wide gap between astronomical and terrestrial happenings, by assuming four "elements" here below (that is, earth, air, fire, and water), and a fifth and entirely different "element" for the celestial or astronomical bodies, a kind of divine "stuff" which exhibited its "perfection" by moving always with a circular motion, whereas earthly "imperfection" was evidenced in rectilinear motion. This mystical supposition was worked out in considerable detail and was amplified by the further assumption that heavy bodies move "down" and light bodies "up." Any criticism, however, of the theories held by the ancient Greeks must be made in the light of the handicaps under which they labored. It is hard for us to visualize even in part how limited knowledge was in Aristotle's day. The astronomical facts as then known could be explained by either the Pythagorean or the Platonic cosmography, and the latter was the common-sense assumption. The facts of physics were so little known that a rational hypothesis in this field was entirely out of the question. Beyond his notable achievement in establishing the scientific method, Aristotle's chief contributions were in other departments of knowledge, not in physics and astronomy. Here he was nearly always more wrong than right, with the unfortunate result that progress in these fields and in those dependent upon them was held back many centuries. Such was the weight of his authority that no one dared question his assumptions and conclusions until after the Middle Ages.

§ 3

But we must not get too far ahead of our story. Plato, Aristotle, Eudoxus, Callippus, Aristarchus, and their con-

tributions take us two or more centuries beyond the pioneer work of Thales and Pythagoras in Ionia and Southern Italy to the ascendancy of Athens and the splendors of the age of Pericles.

Retracing our steps to the beginning of the fifth century B.C., we pause for a moment to observe that by this time Persia had subdued the ancient civilizations of Assyria, Babylon, and Egypt, and had extended its empire to the Indus on the east and to the Mediterranean and Black Seas on the west, the Arabs alone in this vast region remaining unconquered.

The new masters of the ancient world now decided to add the land of the Hellenes to their possessions and mustered their unnumbered hosts for the event. But the Greeks were made of unconquerable stuff in those days and though greatly outnumbered flung back the invaders in several disastrous battles (off Salamis, at Platæa, and in the shadow of Mount Mycale). Previously, at Marathon and Thermopylæ, they had risen to such heroic heights that their exploits there have come down through the centuries as synonymous with the finest in valorous deeds.

The most constructive period of Greek intellectual endeavor now began. History, philosophy, drama, poetry, architecture, and the plastic arts flourished as never before and in some respects as never since. Victory over the most feared of the powers that threatened the Western World stimulated the Greek spirit to its mightiest endeavors. Nor is the influence of Thalean and Pythagorean mathematics of minor importance in these achievements. Greek sculpture and architecture are the admiration of the ages largely because of the symmetry introduced by the new Greek science of geometry.

Many able thinkers on scientific subjects during the early part of this exalted period of Greek history must be passed

over here. The scientific method had not yet been consciously formulated. Speculative discussions of various kinds, centering on geometry, music, the movements of the heavenly bodies, and the composition of matter, were going actively forward. The Pythagorean school continued as an important center of thought, and several other schools had arisen, among them the Sophists, who did much to clarify reasoning processes.

Two men, however, deserve mention as representative of new tendencies in speculation and science at this time. One is Socrates (469-399 B.C.), a carver in stone, who taught that mathematics is barren speculation and that useful citizens of good character are more important than learned men. Socratic teaching ran counter to the prevailing customs of slavery and fixed social classes, for which reason he was regarded as a dangerous radical. Like two of his contemporaries, he suffered martyrdom for his beliefs. At the advanced age of seventy, he was accused of "disbelieving in the gods of the state, of proclaiming other gods, and of corrupting the youth," and was forced to drink the poisonous hemlock. The other man is Hippocrates (460-370 B.C.), the "father of medicine," who influenced scientific advance through his carefully conducted medical researches. He was the first to organize medical knowledge into a unified whole, to make emphatic protest against prevailing superstitious and sacrificial practices associated with the healing art, and to emphasize the curative power of nature.

Now medicine is an art not a science, biology (the study of plant and animal life) being the science upon which medical practice depends; but since the practice preceded, and since a large part of biological advance was later made by physicians, medicine may be regarded as the foster-parent of biology. Practical acquaintance with the structure

of plants and animals dates back to prehistoric man, and a considerable knowledge of herbs and their curative properties was developed in Egypt and Babylon. So biology has ancient forebears, arising as a serious study with the Greeks, although the word "biology" was not generally used until the nineteenth century.

One of the first subjects of speculation with all early peoples has been to ascertain the seat of life and intelligence. The heart was long regarded as this center of vital power. Another theory had it that thought processes originate in the kidneys. Alcmæon, a predecessor of Hippocrates, had made the important discovery that the brain is the organ of sensation and thought, and Hippocrates gave prominence to the idea by making it the basis of much of his work. Aristotle later erroneously disagreed with this conclusion. But Hippocrates in his field was the authority. The medical tradition started by him passed on to succeeding generations of physicians, who through the professional schools received a rough-and-ready training in those branches of biology now known as anatomy and physiology, not along Aristotelian but along Hippocratic lines. The father of medicine and his later followers at Alexandria wielded an influence fully comparable to that of Aristotle and in some respects overshadowing it. It is still said of Hippocrates that he gave the physicians of all time "the highest moral inspiration they have."

It was during the days of Hippocrates and Socrates that Athens rose to supremacy among the Greek city-states under the great statesman Pericles, and that the Athenian school of philosophy came into the ascendancy. Here it was that Socrates and his pupil Plato held their daily discourses, and here it was, at the feet of Plato, that Aristotle received his training.

After a twelve-year voluntary exile, following his

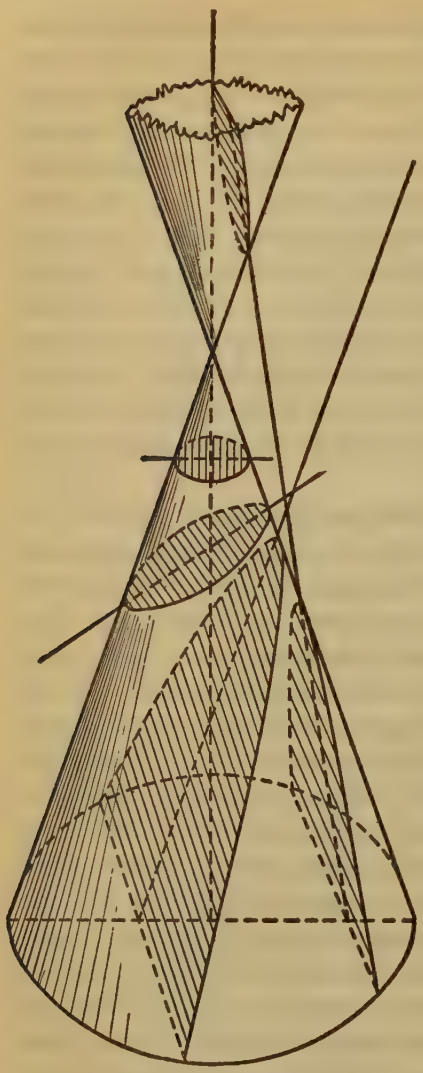
master's martyrdom, during which he doubtless familiarized himself with the learning of Egypt, Babylon, and other early civilizations, Plato (429-347 B.C.) returned to Athens around 387 B.C. to establish a school of learning. Unlike Socrates, his teacher, Plato was born of noble parentage and remained an aristocrat throughout his long career. He was deeply influenced by both Socratic and Pythagorean doctrines and attempted to reconcile them. He followed Socrates in emphasizing intuition and in insisting that sense impressions are inherently unreliable as guides to an understanding of truth. But he denied that mathematics is trifling in character, urging that we acquire mathematical truth by way of the intuition and not through the senses.

Like Socrates, Plato was interested in ethics and politics, and around these subjects he built his famous idealistic philosophy, which holds, in brief, that the intuition furnishes us with ideas or patterns regarding morality, beauty, truth, goodness, and the like, which patterns we can unfailingly follow as guides. The chief fallacy of his teachings lay in two directions: first, in failing to link up the world of "ideas" and "ideals"; and, secondly, in relying on intuition at the expense of sense perception. Plato's knowledge was nevertheless profound. His analysis of ultimate reality was so penetrating that it stimulated speculative thinking to its highest point in that remarkable Greek epoch, finding its greatest expression later in the person of Plato's pupil Aristotle, at whose hands it resulted in the still more penetrating analysis which established the scientific method. It must be remembered that in Plato's day the scientific method, as a deliberate and conscious process, had not yet been born. He simply reduced speculation as such to its lowest terms.

Plato despised material things. His world of "ideas" was

self-sufficient, perfect, fundamental; and the material world imperfect, secondary, and doomed to evil—a conception still widely held. As already indicated, he regarded celestial motions as circular with the earth as an immovable center, and built up his cosmography accordingly. Plato's speculations about the earth covered a wide area, nor were they by any means all fantastic. As a matter of fact some of his conjectures about the geological development of ancient Greece and the Ægean Sea have been remarkably confirmed in recent times. Plato and other Greeks assigned a correct meaning to fossil remains and collected some geological specimens, but geology had to wait many centuries before it became separated from the rest of "natural history" and secured a place for itself.

Plato was, in short, not merely a speculative philosopher. He was a keen observer, and he was also one of the greatest mathematicians among the ancients. Over the door of his famous Academy he is said to have had inscribed the following dictum: "Let no one presume to enter here unless he has a taste for geometry and the mathematics." To the formulæ that Thales, Pythagoras, and others had worked out regarding lines, triangles, and the circle, Plato made important additions, especially regarding the properties of conic sections, that is, of the ellipse, parabola, and hyperbola. Plato observed that if a cone is cut by a plane certain peculiar curves are produced, some looking like flattened circles and others spreading out indefinitely without closing. He studied these curves and with another geometer of the period reduced them to three types. In Plato's day, the parabola, the ellipse, and the hyperbola had nothing more than a theoretical meaning. Two thousand years later Kepler utilized their properties to work out the laws of planetary motion. Thus, as has often happened, the theoretical came ultimately to have a definite practical



CONIC SECTIONS

significance. Plato's emphasis on theory and intuition, therefore, is of vital importance.

In the footsteps of Plato followed his pupil Aristotle (384-322 B.C.), the greatest of the Greeks, despite the scores we have already marked up against him. Born at Stagira in Macedonia of wealthy and prominent parents, son of a celebrated physician to the king, Aristotle entered Plato's Academy, it appears, at the age of seventeen. Here he is said to have studied for twenty years and to have laid a solid foundation for his remarkable career, a career of learning and wisdom that has hardly been equaled since. It is said that during his student period his thirst for knowledge was so great that he devised means of keeping himself awake at night to pursue his work. As he lay in bed reading, he would hold a leaden weight in one hand extended over a brass

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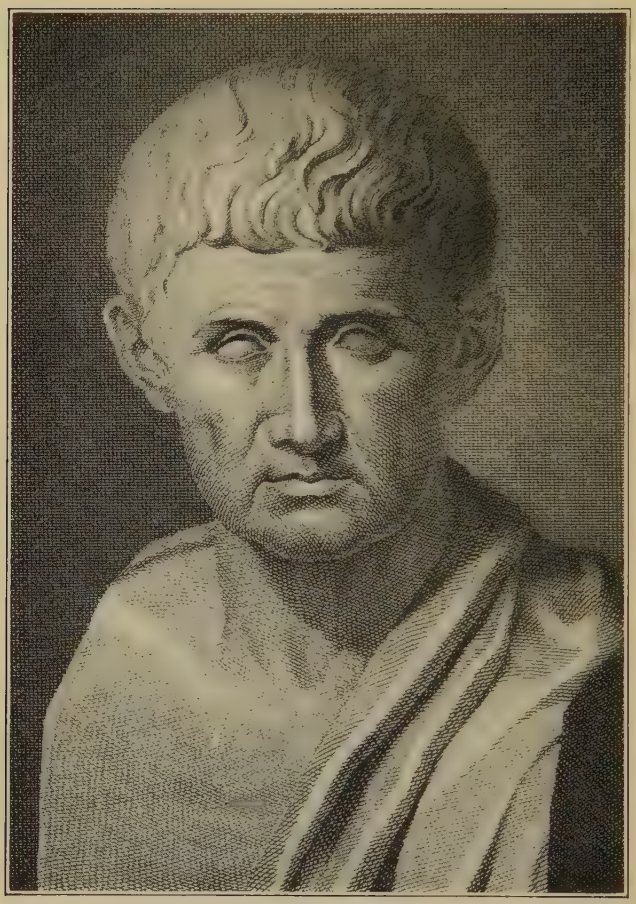


ARISTOTLE

basin resting on the floor. Should he begin to grow drowsy, the weight would slip from his fingers and strike the basin, waking him up again.

Upon leaving Plato's Academy, Aristotle became tutor to "Crown Prince" Alexander. After the latter ascended the throne of Macedonia, Aristotle, then forty-nine years old, returned to Athens and opened his famous Lyceum, which came to be known as the Peripatetic School, because of the fact, according to one version, that he imparted knowledge to his pupils while walking up and down a covered portico or *peripatos* situated within the grounds of the Lyceum. For the next twelve years Aristotle taught every branch of knowledge then known, and through the aid of Alexander the Great engaged upon research investigations on a scale unsurpassed to this day. The king placed hundreds of thousands of dollars at the Stagirite's disposal, and at one time a thousand men were scattered throughout Greece and Asia making observations for him. In this way, 158 political constitutions and innumerable specimens of plant and animal life were carefully analyzed.

Aristotle's first and greatest bid for fame came as the critic of Platonic speculation and intuition. Opposing the idea that the senses cannot bring nature's secrets to us, and still appreciating the danger of falling into false reasoning or depending upon the unaided senses, he set about devising the principles of scientific procedure which, as outlined in the preceding chapter, constitute the foundation-stones of the edifice of science. From his day to our own, observation and experiment have been the handmaids of scientific advance. Along with his discovery and analysis of the scientific method, Aristotle organized all existent knowledge into a unified whole and arranged it into convenient compartments. His classification was so logical and comprehensive that it was not superseded till modern times.

Regarding Aristotle's false physical and astronomical theories, we have already spoken. In politics, he thought of slavery as a natural institution and of monarchy as the best form of government. In ethics, he emphasized the golden mean. As for the mind, he regarded it as an empty tablet upon which God engraves His will. Regarding religion, he believed in monotheism as against the prevailing polytheism. In all these beliefs he forecast the new world of Rome and the advent of Catholicism, into which his theories fitted admirably. In these matters, however, his speculations were not one whit better than those of Plato. In fact, in some respects they were worse, and in other respects he accepted Plato's conjectures without question.

Aristotle was nevertheless a keen observer and experimenter, and we have still to examine the field in which his greatest scientific contributions were made. This was the field of biology. It has already been noted that he disagreed with Hippocrates regarding the seat of intelligence in man, but this was due to the current confusion of "intelligence" with "life." Aristotle practised vivisection and ascertained experimentally that the brain when cut or burned does not feel. How then, he argued, can it be the seat of life? Furthermore, he had made experiments with the embryo chick and had watched the beating of its heart long before the brain began to develop. Hence he concluded that the heart is the seat of life (and intelligence), and defied the medicals, who nevertheless later proved him to be wrong with respect to intelligence at least. Here it was the inadequacy of knowledge that led Aristotle astray, despite his carefully executed experiments. In other respects, however, Aristotle's biological conclusions were remarkably sound, and in one exceedingly important instance he proved Hippocrates to be in error. The latter taught that solid food goes into the stomach, but that liquids go into the lungs.

Aristotle in his experiments showed clearly that both liquids and solids enter the stomach. That such facts, commonplaces to us, were then in dispute, gives some faint inkling of what the limitations of knowledge in Aristotle's day must have been.

In the main, despite Hippocratic medical advances, there was no biology worth speaking of before Aristotle. He has been rightly called the father of natural history (as, among other things, biology and geology were then, and for many centuries afterward, designated). It was the Stagirite who first drew attention to the distinction between inorganic and organic matter, asserting that the latter is impelled by an inner principle and constitutes an ascending scale, from lower to higher forms, with man at the top, thus forecasting the theory of evolution. He made many direct studies of existing organisms, and his descriptions and analyses, so far as they went (without the aid of the microscope which came many centuries later), leave little to be desired. Just as he created a full-grown set of scientific and logical principles, so he arrived at many important biological generalizations, some of which still hold to-day. Theophrastus, a pupil and co-worker of Aristotle, made a deep study of plants, his list of botanical observations and discoveries constituting the rudiments of scientific botany. With Aristotle's work on animals and that of Theophrastus on plants, "biology emerged from the shadows of the past and took concrete form."

In all this, however, Aristotle knew he was making but a beginning, for he says: "I found no basis prepared; no models to copy. . . . Mine is the first step, and therefore a small one, though worked out with much thought and hard labor. It must be looked at as a first step and judged with indulgence." It was indeed only a start, even though a magnificent one. Aristotle did not realize that physics and

chemistry had to grow to maturity and that the microscope had to be invented before the foundation facts of biology could be revealed. He did not know that, except for the Hippocratic school of physicians in Alexandria, centuries upon centuries would elapse before another worth-while forward step would be taken in this field.

Aristotle's chief claim to fame rests, after all, upon his discovery of the scientific method. He insisted upon observation and induction, which means the formulation of general principles from concrete facts, and held that errors arise not so much from faulty sense organs as from faulty interpretations of the data observed. Subordinating his deductive logic to that end, he says: "We must not accept a general principle from logic only, but we must prove its applicability to each fact; for it is in facts that we must seek general principles, and these must always accord with facts, from which induction is the pathway to general laws."

Had Aristotle only followed his own advice more closely, instead of being carried away on the wings of speculation as often as he was, in his keen desire to encompass the whole of truth! But the establishment of the scientific method is enough. What more epoch-making achievement has any other man to his credit?

§ 4

The accomplishments of the Ionian pioneers and of the great Athenians have been briefly surveyed. The scene now shifts to the city of Alexandria, which Alexander the Great had founded after his conquest of Egypt in 332 B.C. By 300 B.C., a remarkable center of learning had developed here. Alexandria became the intellectual and commercial gathering-place of the world. Under the influence of enlightened rulers, a great museum was founded; scholars

were entertained at public expense; thousands of students were attracted; a botanical garden, an enormous zoölogical collection, and an anatomical building were established; an astronomical observatory was erected; and a library of seven hundred thousand volumes was brought together. Even in modern times, little can compare with this colossal effort to organize scientific endeavor; and it bore rich fruit. Ionia had accomplished its pioneer mission; the philosophic speculations of Athens had gone on unabated despite Aristotle and were leading finally to barren sophistry and skepticism; so that the mantle of scientific advance fell upon Alexandria. Here the Hippocratic school of physicians flourished; here astronomy struggled along in spite of being burdened with a false cosmography; and here, most important of all, the foundations of mathematics were brought to completion.

Of the Hippocratic school, four Alexandrian physicians stand out prominently. Erasistratus, the first of these, completed a great work on the anatomy of the nervous system about 300 B.C., which conclusively disproved Aristotle's theories regarding the brain. A contemporary of his, Herophilus, also did notable work in human anatomy and is said to have practised vivisection on condemned criminals. The disemboweling and embalming of the dead, an Egyptian custom carried on in Alexandria at that time, helped to correct many grotesque misconceptions previously held regarding the inner constitution of the human body. Some five hundred years later came the still more extensive researches of Galen, physician for a time to the Roman emperors Commodus and Marcus Aurelius. Galen (131-201 A.D.) obtained accurate neurological knowledge by experiments on the lower animals and gave demonstrations to his pupils in Rome. He wrote extensively and brought together all the work of his predecessors, organizing it anew into a

logical system and adding his own original material. His books on anatomy and physiology came to be widely used as texts and remained the authoritative standards for fifteen centuries. In the meantime, around 64 A.D., Dioscorides, a military surgeon under Nero, had written a medical botany which, because practical, overshadowed the more penetrating researches of the Aristotelian Theophrastus. Up to the seventeenth century most botanical writings were based upon those of Dioscorides.

In astronomy, although falling back considerably from the high mark set by the Pythagoreans and especially by Aristarchus, Alexandria developed some notable savants. Further progress was not completely arrested by the acceptance of a false cosmography, for facts could still be gathered, and the accepted theory of the universe, though erroneous, was mathematically tenable in the light of existing knowledge of the heavens and thus was a step in advance.

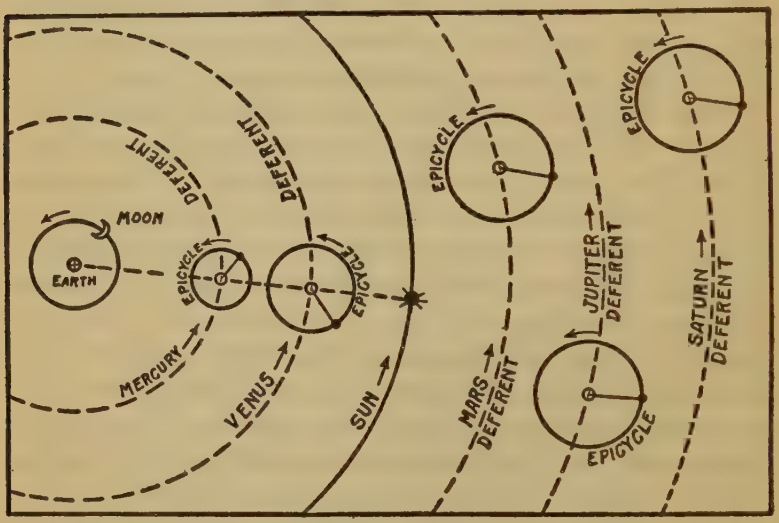
Two noted astronomers arose in the city of Alexandria, Hipparchus and Ptolemy. Hipparchus (born about 150 B.C.) was renowned as a mathematician and as an astronomer. In the latter field he improved the construction and design of astronomical instruments, especially the astrolabes, which had sights similar to those used on rifles to-day, and which were the chief instruments employed for observing astronomical occurrences before the invention of the telescope many hundreds of years later. With his slightly improved implements Hipparchus made observations of the sun, moon, and planets, with such a degree of accuracy that none better were forthcoming for nearly sixteen hundred years. In making his calculations he felt the need of an additional tool for measuring angles and ascertaining their properties, for which purpose as a short cut he invented the rudiments of trigonometry.

The greatest astronomical discovery of Hipparchus was his observation that the pole of the earth as it turns on its axis varies a little, and he calculated that each pole thus described a circle every thirty-six hundred years, which phenomenon is now called technically the precession of the equinoxes. In arriving at this generalization he employed an important kind of coöperation and comparison of astronomical observations. He compared his own observations with similar ones made a hundred and fifty years before. In the same way his observations have since formed the basis of later additions to astronomical knowledge.

Hipparchus also corrected the calculated length of the year to within five minutes of its actual length, and produced the first comprehensive catalogue of the stars, measuring the position of 1080 of them and distinguishing six magnitudes of brightness. His method of indicating star brilliance has persisted to our own times, and his catalogue proved an immeasurable help to astronomers of later centuries. He improved considerably on the mathematics of calculating eclipses, and, following Apollonius, "the great geometer" among the Alexandrian mathematicians, laid the foundations for the mathematical system of planetary motion perfected by Ptolemy three hundred years later.

Ptolemy (100-170 A.D.) is best known by his exhaustive astronomical treatise called the "Syntaxis," wherein he describes the accomplishments of his predecessors, especially Hipparchus, and explains the system which bears his name. Accepting the Aristotelian conception of an immovable earth around which the celestial bodies were supposed to revolve with perfect circular motions, and utilizing a great number of subsidiary geometrical devices such as epicycles, he represented the movements and positions of the sun, moon, planets, and other stars in such a way that they fitted recorded observations with a considerable degree of

accuracy. This was simple enough with the sun and the fixed stars, for these do appear to move in circles around the earth once daily, as the earth turns on its axis, and to move about the earth in another direction once yearly as it revolves about the sun. The movements of the planets, which are irregular as viewed from the earth, were not so easy to account for in his system. It took considerable mathematical ingenuity to work them in.



THE PTOLEMAIC SYSTEM

The Ptolemaic system is a stupendous piece of astronomical mathematics. Even Copernicus, fourteen centuries later, though he simplified the arrangement by assuming the earth to revolve about the sun rather than vice versa as Ptolemy had assumed, failed to add anything in mathematical accuracy, for he still retained the hypothesis of circular orbits. It required the deeper knowledge and the genius of a Kepler to achieve greater accuracy by assigning elliptical in place of circular courses to the planets. With

Ptolemy the Greek period of astronomical advance comes to an end. There is nothing of significance to record in this department of scientific endeavor for another fourteen hundred years.

In mathematics, Alexandria produced the great Euclid, the first of a splendid line of mathematicians who got their inspiration through him—Archimedes, Apollonius, Hipparchus, Ptolemy, Diophantus, and others—two of whom were also great astronomers, as has just been pointed out. Euclid, who came into prominence about 300 B.C., or soon after Alexandria rose to importance, was well liked by the reigning king, who asked him on one occasion for a short-cut method of studying geometry, to which Euclid made the famous reply that "there is no royal road to geometry."

Euclid's main contribution to scientific advance consisted in fashioning into a complete system the science of geometry as it had developed at the hands of a long line of Greek mathematicians, beginning with Thales and Pythagoras and advancing with Plato and others to his own time. Euclid added some new theorems of his own, but his outstanding achievement was the manner in which he used the Aristotelian logic to bring together the whole scheme of geometric reasoning. He arranged the subject-matter with such thoroughness and clarity that Euclid's "Elements," as his treatise is called, has stood the test of time to the present day.

We all know what plane and solid geometry now encompasses. It takes up lines and angles and circles and plane and solid figures of various kinds and analyzes their properties. Little of this has been changed since Euclid's time. Euclid also began the development of the theory of "limits," which theory may be regarded as the starting-point of what we to-day call higher mathematics. His explanation of the idea is quite simple and is as follows: Inscribe any regular

figure, say a hexagon, in a circle. It is obvious that the perimeter (the sum of the sides) of the inscribed hexagon is somewhat shorter than the circumference of the circle. Now increase the number of sides in the figure to eight, to sixteen, to one hundred, and so on. At each successive increase in sides, the perimeter of the polygon becomes longer and approximates more and more to the length of the circumference of the circumscribed circle, which the perimeter, however, can never quite equal. The circumference, therefore, is the "limit" of the perimeter of the inscribed polygon as its sides increase in number. Archimedes, a famous pupil of Euclid and ranked as the greatest of the Greek mathematicians, applied this idea of limits successfully to working out the area of a parabola cut off by a line perpendicular to its axis, and to establishing other important properties of conic sections.

Archimedes (287-212 B.C.) was born in the Greek city of Syracuse in Sicily but was educated in Alexandria. After his course of study along Euclidean lines was completed, he returned to Syracuse and spent the remainder of his days in further study, experiment, and research. He quickly became famous, and justly so, for in many respects this genius was the greatest of the Greek thinkers. It is to Archimedes that we owe the formulation of the value of π, the ratio of the circumference of a circle to its diameter; the method of finding the area of a sphere; the construction of the spiral that bears his name; and many other important mathematical principles and formulæ. He wrote exhaustively on every branch of then-existing mathematics, and his treatment was always original and advanced the subject. Especially in applying his mathematical knowledge to physical phenomena is he renowned to-day. For great as was his mathematical genius, he was even greater as a physicist.

He it was who said, on discovering the principle of the lever, "Give me where to stand and I will move the earth."

Who has not heard the story of Archimedes jumping from his bath on the discovery of what to-day is a vital principle of hydrostatics, and running naked through the streets of Syracuse shouting *"Eureka! Eureka!"* (I have found it! I have found it!). In his absent-mindedness he had allowed the bath-tub to get full to the brim before stepping in, and, when he entered, the bath overflowed. Suddenly he realized that he had found a method for measuring the bulk of an irregular object by measuring the amount of water displaced, for he was working on just such a problem at the time. Hence his enthusiasm. With respect to his theories of the lever and of hydrostatics, eighteen hundred years were to elapse before any further advances are recorded.

Archimedes devised many ingenious mechanical contrivances. One was his famous water-pump, known as the screw of Archimedes, which was shaped like a corkscrew, and which, set at an incline and rotated, raised water from a lower level to the required height. Another device was his "burning-glasses" or arrangement of gigantic mirrors, with which he is reputed to have set an enemy fleet of ships afire by concentrating the sun's rays upon them.

Syracuse finally fell into the hands of the Romans, but such was Archimedes's fame that orders had been given not only to spare his life but to accord him every honor. Despite these orders, however, he was killed in the sacking of the city. A Roman soldier, finding him (it is said) absorbed over a geometrical figure and getting no answer to a demand for his name except to be told to begone and not spoil his diagram, slew him on the spot. Archimedes lived in a period of turmoil, but his achievements in mechanics were exceedingly important and would have marked a turning-point in

world history could they have been followed up. The Aristotelian misconceptions regarding physics and the darkness of the Middle Ages laid a heavy covering of prejudice over Archimedes's work and that of his followers, and this was not lifted till after Galileo's day around 1600.

The mathematical contributions of Hipparchus, in creating trigonometry, and of Ptolemy, in applying the principles of mathematics to astronomy, have already been touched upon. Hipparchus lived about a hundred years and Ptolemy three hundred and fifty years after Archimedes. Another three hundred years elapsed before Diophantus, the last of the prominent Greek mathematicians, appeared on the scene.

Diophantus, who lived in the early part of the fourth century A.D., may be regarded as the founder of algebra. This subject had developed as a form of logical reasoning having to do with finding the value of an unknown quantity from certain data supplied, which reasoning had been abbreviated from time to time until symbols came to displace words. At first the statement with respect to the unknown quantity had been written out in full, the only simplification arising from the use of the Aristotelian principles of deductive logic. Next the unknown quantity was abbreviated and a symbol (like x) came to be used to represent it. Finally symbols were created, also, for the common operations of addition ($+$), subtraction ($-$), equality ($=$), and so on, although the symbols that are in use to-day were not adopted till recent centuries. Diophantus brought the Greek beginnings together, and laid the foundations for later algebraic developments during the Middle Ages by the Arabs and the Hindus.

In mathematics, the Greek genius bore its richest scientific fruit. Other departments of inquiry fell under the blight of false hypotheses, but mathematics proceeded along right

lines and advanced to full fruition. With the exception of Socrates, all the great Greek thinkers found a place for this science in their scheme of things, whether that scheme depended upon the evidence of the senses or upon the promptings of the intuition. And, it should be understood, only as mathematics developed further and was applied to other fields, did these lose their speculative encumbrances and become in true measure sciences. The seal of mathematics was of necessity the first seal of the Book of Nature that had to be broken before the others could be loosened.

§ 5

The golden era of Greek learning came to an end with Galen on the one hand and with Ptolemy and Diophantus on the other. Any attempt to sum up the achievements of the Hellenes leaves much to be desired, but a few conspicuous facts will bear epitomizing. First, the Greeks gave to the world an incomparable spirit of inquiry and discovered and developed the scientific method of careful observation and experiment. Second, by means of this spirit and method they gathered together and bequeathed to posterity their marvelous legacy of observed facts in biology, physics, astronomy, and mathematics. Third, they began the formulation of general principles from the observation of particular occurrences, perfected the rules of deductive logic, and set the science of mathematics on a solid foundation, thus forging the necessary tools for further scientific advance. The Greeks struggled mightily to unseal the Book of Nature, discovered the way to break its seals, broke the first one, and deciphered enough of the contents thus disclosed to enable succeeding generations after the Middle Ages to grapple successfully with the other six, the seals of astronomy, physics, chemistry, geology, biology, and psychology.

CHAPTER III

THE DARK AGE OF SCIENCE AND THE REVIVAL

§ 1

WHILE the ancient Greeks were engaged in their magnificent endeavor to unseal Nature's Book, other races, like the Persians in the fifth century B.C., were writing feverishly in the Book of Man. Conquest and subjugation are the theme upon which these other races dwelt, and around which their ethics, politics, jurisprudence, economics, and religion shaped themselves. Predatory occupations leave little room for impartial inquiry and high intellectual endeavor. After Greece fell under the blight of Rome, therefore, Nature's Book came to be neglected and, in Europe, was for a long period lost to view.

Alexander the Great in the fourth century B.C. had written large and had wept, it is said, because the human blood he used for writing-fluid had dried on his pen. The Cæsars followed Alexander, writing their own version and building their society accordingly. Their empire had a glorious reign but an inglorious ending, whereupon sturdier races seized the pen from the lifeless fingers of the Cæsars, scratched out a large portion of what had been written, and in more primitive fashion wrote anew. Beginning with the third century A.D. and continuing for several hundred years thereafter, wave after wave of Northern barbarians broke against the Roman Empire—Franks, Goths, Vandals, Huns, and other races—until

NORTH SEA
BALTIC
ENGLAND
CAMBRIDGE
OXFORD
(GERMANY)
(RUSSIA)
PARIS
FRANCE
TURKESTAN
CASPIAN SEA
PADUA
MONTPELLIER
BOLOGNA
ADRIATIC
ITALY
SPAIN
(BULGARIA)
(SERVIA)
BLACK SEA
CONSTANTINOPLE
(BYZANTIUM)
NICAEA
ROME
MACEDONIA
SALERNO
GRANADA
GREECE
AEGEAN
ASIA MINOR
STS. OF GIBRALTAR
ATHENS
TAURUS MTS.
EUPHRATES
TIGRIS
BAGDAD
PERSIA
AFRICA
CRETE
SYRIA
MEDITERRANEAN SEA
JERUSALEM
ALEXANDRIA
EGYPT
ARABIA
NILE
RED SEA
INDIA
THE MEDIAEVAL WORLD

Spain, France, Italy, and most of the rest of Western Europe were completely overrun.

Farther East the impact of these tribes had been at first much less severe, so that out of the ruins of the Roman power there arose the Byzantine Empire, with its capital at Constantinople, which for a time held Greece, Asia Minor, Syria, and Egypt together in some semblance of civilized order and under energetic rulers even expanded its domain somewhat.

By this time Greek science had died out everywhere in Europe. The Roman contempt for it and the hostility of the church, which had already taken firm hold on the empire before its disruption, had stifled independent thought. By 450 A.D. Hellenism had practically disappeared even in Alexandria, and the last Greek schools in Athens, sterile though they had already become, were closed by imperial edict in 529. The Dark Ages had settled upon Europe.

§ 2

But soon after the beginning of the seventh century a new power made itself felt in the East. Out of Arabia came the Mohammedan Arabs, who up to this time (when Mohammed inspired them to world conquest in the name of Allah) had been content to pursue their circumscribed nomadic ways. With fanatic zeal they now swept north, east, and south intent on writing a different version of the Book of Man than had ever been written before. "Confess the True God, pay tribute, or die," was their battle slogan. A new world religion had been born to take issue with Christianity.

In less than twenty-five years Persia, Syria, and Egypt were in the hands of the Mohammedan conquerors. Alexandria fell in 641, and its great library and museum were destroyed. By 750 the Arabs had crossed the Indus and

By Pieter Breughel. 1558

A MEDIEVAL ALCHEMIST SHOP

UNIVERSITY OF ARIZONA
LIBRARY

had penetrated Turkestan (out of which the Turk, converted to Mohammedanism, was later to come), had pushed the Byzantine Empire beyond the Taurus Mountains, were occupying all of North Africa, and had crossed the Straits of Gibraltar into Spain. For the next three centuries, these peoples held sway over a vast area, giving place finally in the east to the Seljukian Turks, who injected new vigor into the Mohammedan cause and carried the threat to Christendom to the gates of Constantinople in 1071, thus stirring up the Crusades. How the Seljukians gave way to the Mongols under Jenghiz and Kublai Khan, the greatest conquerors of all time, and how these in turn were succeeded by the Ottoman Turks, who in the fifteenth century pushed the Byzantine Empire still farther westward until Bulgaria, Serbia, Macedonia, and Greece were in Mohammedan hands and Constantinople had fallen, we cannot discuss here. Disordered scribbling in the Book of Man continued throughout the Middle Ages and beyond, not only in the East but wherever civilized man attempted to establish himself. At this point our chief interest lies in the achievements of the Arabs, not as conquerors and plunderers, but in more constructive capacities.

It has been thought in some quarters that the Arabs wiped out the Hellenic culture in the East when they destroyed the library and museum at Alexandria in 641 A.D. This is by no means true, although many valuable records were lost at that time. Nearly a thousand years before, Alexander the Great through his various settlements, and the Greek traders and colonists before and after him, had definitely planted Hellenism in Central Asia as well as in Northern Africa, and the Hindus beyond the Indus had during the millennium that followed made notable additions to it, especially to those portions of mathematics in which the Greeks were weakest, namely,

arithmetical notation and algebraic symbolism. The important scientific achievement of the Hindus was the development of the so-called Arabic scheme of numerals, our present number system, which with their invention of the symbol zero made decimals possible and simplified computations immeasurably.

When the Arabs took Alexandria, Greek science was already on the wane there, whereas the Hindu-Hellenic culture was flourishing in Central Asia which the Arabs had likewise subdued. Furthermore, scholars of other races, notably among the Jews, were scattered throughout the length and breadth of the Arabian Empire and were keeping alive the Greek ideas during the early centuries of the Mohammedan conquests. These scholars were also making some contributions of their own. Finally the Arab mind itself, after the first excesses of Mohammedan fanaticism had spent themselves, turned to intellectual pursuits and for a period rose to some degree of creative power.

After 750, successive Arabic rulers patronized learning, drew upon the Hindu-Hellenic culture, collected Greek manuscripts that had become scattered abroad with the closing of the Athenian schools in 529 A.D., ordered the writings of Aristotle, Euclid, Ptolemy, and other scholars translated into Arabic, and developed a center of learning at Bagdad where mathematics, astronomy, philosophy, and medicine saw some advance.

In 830 Alkarismi, an Arab, wrote a book on algebra based on the Hindu developments and gave the science its name. Somewhat later, Alhazen, another Arab, wrote a book on optics and noted, possibly for the first time, that spherical sections of glass have magnifying power. By means of Hindu improvements in arithmetic and trigonometry, the Arabs were enabled to make more precise observations in

astronomy, although their attempts to improve upon the Ptolemaic theory of the solar system proved unsuccessful.

The Arabic people rose to their greatest heights in Spain, where mixed with North African stock they came to be known as the Moors. During the ninth and tenth centuries this section of the Mohammedan world acquired an enlightenment which was not equaled in Christian Europe until seven or eight hundred years later. While the Moorish culture lasted, and that unfortunately was not very long, schools were established, Hindu, Greek, and Arabic science flourished, and the practical arts saw an amazing development. Yet, beyond the Hindu contributions, there was little of permanence in this display. The occult and the fantastic were inextricably mixed with the scientific. Alchemy and astrology were pursued with even greater diligence than were mathematics and astronomy. The chief accomplishment of the Arabs in Spain as elsewhere was to keep the torch of science lighted until Christian Europe was ready to receive it. Their creative effort had already spent itself completely by the middle of the twelfth century, when Bhaskara, a Hindu mathematician, brought together the achievements of his countrymen in a notable treatise which systematically presented an improved algebraic symbolism and practical applications of the decimal notation. By the end of the thirteenth century Christendom was pushing the Moors out of Spain. The Moors held on in Granada for a time longer, but soon they and their civilization disappear, and astonishingly few evidences of their once high culture remain to-day. In acting as a leaven upon the ignorance and inertia prevailing in Christian Europe, however, the Arabs performed a most important service.

Turning now to what was happening in Europe during these centuries, the rise of the church to power is the most

important event to be noted. Everyone is familiar with the fact that Christians were persecuted by the Roman emperors during the early centuries of the Christian era. What is not so generally appreciated is that with the ascension of Constantine the Great to the throne, Christianity received official sanction. Perceiving the value of this world religion as a force to unite peoples of different races, Constantine called a general council of the church at Nicæa in 325 and saw to the adoption of a unified system of doctrine. The Nicene Creed combined the simple and lofty teachings of Jesus with the traditions and practices of an earlier and cruder worship. It probably had to do this to gain adherents among barbaric peoples who still practised primitive ceremonials and sacrifices. But it at least achieved unity of belief, for Constantine immediately began insisting upon conformity; by 400 the Nicene Creed was unquestioningly followed everywhere. From that time forward Christianity became a power of the first order in the Western World. It was in fact the main cohesive force that existed for many centuries after the collapse of the Roman Empire, falling heir finally to the Roman tradition by establishing itself in Rome, and at various times attempting to secure political as well as ecclesiastical control over the whole of Europe.

In the political sphere during the early Middle Ages, there is little but confusion and darkness to be recorded of Europe. Spain was wrested from Christendom at the beginning of the eighth century. Franco-Germany was united for a brief period under Charlemagne, who, appalled at the ignorance of the people, attempted to establish schools for their instruction. He also endeavored to revive the tradition of the Roman Cæsar in the West in his efforts to control Italy and the pope, and he did much to Christianize the various barbarian races then inhabiting Europe. But in

these efforts he provoked a counter-movement from the north which disrupted his well laid plans. Once more came sturdy barbarians—this time Northmen from Scandinavia, nomads from the Great Plain of northern Asia, Slavs from the northeast—who swept down upon Christendom and brought with them a new political chaos in the ninth and tenth centuries, to be followed in the eleventh by another futile attempt (by the Normans) at consolidation. And so it goes on, only the Byzantine Empire remaining intact, though steadily shrinking in size, and the church alone making progress, converting the barbarians almost as fast as they appear and after the year 1000 encouraging pilgrimages to Jerusalem, the Mohammedan rulers in the East showing little active desire at that time to interfere.

Intellectually, Christian Europe was one vast desolation. As a result of the church's insistence upon unquestioning obedience, a cringing dependence upon the authority of the written word had come into being. Knowledge came to be regarded as complete. Nothing new, it was maintained, could possibly be added. The ecclesiastics considered themselves the sole guardians of the truth, and anyone who dared question their priestly omniscience was summarily dealt with. Most of the ignorance and superstition of the Dark Ages, making due allowances for the chaotic condition of governmental affairs and the barbarous state of the culture of the latest invaders of Europe, arose from this blind acceptance of theological authority, for within the monasteries of that day a number of the illuminating Greek writings lay hidden, and there they remained for centuries. Later, when these writings did emerge, they were at first invested with the same unreasoning and unquestioning authority.

To be sure, the Hindu-Arabic-Hellenic culture was now seeping through from Spain, and the Greek writings were

here and there surreptitiously examined. But as yet no spirit of independent thinking became noticeable. Where other than church dogmas were followed, they were the fantastic and the mystical. Europe had sunk into an abyss of mental subserviency and superstition, of which weird and bizarre practices—magic and the black arts—were natural by-products. Astrology and alchemy came to be widely followed, not in any spirit of scientific inquiry, but as short-cut cabalas for securing perpetual youth or easy riches. Such was the condition of Europe, a blind dependence upon the authority of the written word, ecclesiastical and otherwise, and a wide practice of charlatanism, when the Seljuk Turks displaced Arab authority in the East, virtually closed the routes of pilgrimage to Jerusalem, and, crossing Asia Minor, threatened Constantinople in 1071.

Europe had already had its taste of the kindred of the Turks in Russia and elsewhere, and although the Byzantine Empire and Western Europe had never been on friendly terms before, the whole of Christendom now became stirred with a common fear. The Church of Rome found Europe ready when it launched the Crusades in 1095, and these military expeditions continued intermittently for two centuries. Their objective, in the East, was to free Jerusalem from Mohammedan control, an objective never permanently attained; in the West, to drive the Moors out of Spain and convert the pagans in the Baltic and other outlying regions to Christianity. Here the wars of the Cross succeeded.

§ 3

But in launching the Crusades the church inadvertently let loose forces which were eventually to undermine her authority. The warriors of the Cross left for the East and for Spain ignorant and obedient believers; they returned sophisticated and skeptical. A new world had been opened

to them. Under an alien religion, which also professed the One God, evidences of culture and civilization had been noted which aroused resentment against the intellectual bonds with which the Church of Rome had enslaved Christendom. The Crusades also helped to consolidate the national as opposed to the ecclesiastical spirit; France, England, Germany, and Spain now began to develop independently. But the most important effect of the wars of the Cross was the partial unshackling of the intellect, which Emperor Frederick II exemplified when he called to his Sicilian court Mohammedan and Jewish as well as Christian scholars, introduced Arabic numerals, decimals, and algebra to Christendom, and had Aristotle translated from Arabic into Latin.

With the twelfth century centers of learning, called universities, began to spring up here and there in Western Europe—at Paris, Oxford, Cambridge, Montpellier, Bologna, Salerno, Padua, and other points—and the study of the Greek writings was furthered. The theologians themselves began to dust off and look into the manuscripts which had been lying unused on the shelves of monastic libraries, and after a time the cloak of apostolic succession was thrown to Aristotle, whose teachings (good and bad alike) now came to be followed as blindly as the earlier church dogmas had been before. Students flocked to the universities from every corner of Europe. Greek mathematics, astronomy, and philosophy were partially revived.

Chief among those who now became active in the spread of the Hindu-Arabic mathematics, the rousing of the minds of the people, and the promotion of a fuller revival of Greek learning, were the Italians (especially Pisano, Dante, and Petrarch), but in all this the spirit of free and independent research was still lacking. There was virtually no tendency here to search for new truth.

It remained primarily for an Englishman to dig beneath Aristotle's observations and speculations to his methods, rediscover the scientific approach to knowledge, and urge the need for further investigations of natural phenomena. This great medieval seer, who came several centuries before his time to prepare the way for the real awakening which finally came to Europe, was Roger Bacon (1214-1294). His was a thankless task. Persecuted time and again and thrown into prison for his "heresies," Roger Bacon reached the end of a long life with these words on his lips: "I repent of having given myself so much trouble to destroy ignorance." The trouble, however, was not in vain, even though three centuries elapsed before his efforts came to full fruition.

Born into a wealthy family of the English aristocracy, Roger Bacon received the best education then available. At Oxford he stood out as a student of unusual ability. He soon saw the inadequacy of current Latin translations of the Greek writings, whereupon he set about mastering the Greek language. From Oxford he went to Paris, at that time the intellectual center of Europe, and absorbed all the University of Paris had to offer. At the age of thirty-six he returned to Oxford and began gathering books and apparatus for his own original researches, expending for this purpose in twenty years about ten thousand dollars. In addition to Greek and Latin, he studied Hebrew, Chaldaic, and Arabic and mastered much of the knowledge of these peoples. He traveled extensively, had many influential friends (some of them bishops and archbishops), and joined the powerful order of Franciscan friars, within which he secured some protection from persecution.

For a time Roger Bacon lectured at Oxford, where he lashed with bitter terms the many pretenders and charlatans

who posed as men of learning both within and without the church. He went so far as to write to the pope (Innocent IV) on the need of a reformation. As a result of these activities Bacon was brought to trial on charges of heresy and of "dabbling with the magic arts," a blanket charge applying not only to magical practices but to all forms of experiment with retort and crucible, instruments which Bacon employed in his researches. The outcome of the trial was an imprisonment of ten years. But Bacon's spirit remained undaunted. Though broken in health, he nevertheless kept himself informed on current events while in prison, wrote many letters to his friends, and continued his researches as best he could without instruments.

Upon the election of a new pope (Clement IV), Bacon petitioned for release, offering in advance, "as far as the impediments he laboured under would permit, and his memory would allow, to deduce a regular system of true philosophy to the utmost of his power." Bacon was playing a trump-card in thus petitioning, for he was aware the new pope was very much interested in philosophy. His offer was accepted, and, still a prisoner, with few books and no assistance, he produced in eighteen months three treatises which have since become historic and which secured his release in 1268.

Bacon returned immediately to Oxford and with renewed energy plunged into his researches. In three years he produced another important work; and his fame continued to spread, much to the alarm of the clerics who dared do nothing while the pope was friendly, and of the quacks and charlatans whose fraudulent activities he was baring to the light of day. Then came the death of Pope Clement, and Bacon's enemies once more succeeded in arraigning him on the charge of "dabbling with the magic arts." After ten years of freedom, he was again imprisoned. He was now

sixty-four years old, but his indomitable courage remained unshaken. Despite his lack of facilities, he continued to write on a wide range of subjects during this second confinement, which lasted fourteen years. He was released in 1292, an old man of seventy-eight. Yet even then this remarkable savant was by no means broken, for during the two years between his release and his death he wrote another great work.

Turning to Bacon's contributions to science, one must call to mind again that he lived in an age of intellectual darkness, when reliance on the written word was still supreme, and when it was believed that planets affect the destiny of men (astrology) and that base metals can be transmuted into gold by a process of hocus-pocus (alchemy). Roger Bacon showed many supposed magical effects to be due to natural causes. The most influential people of his day believed the earth flat. Bacon had studied the writings of the ancient Greeks and agreed with them that it is round. He asserted the possibility of sailing westward to India, and his writings had a marked influence on Columbus, two centuries later. Bacon wrote of pulleys, lenses, gunpowder, self-propelled vehicles, under-water craft, and the flying-machine. It is held on good authority that he used a crude form of telescope, and it is certain that he used the simple microscope. Speaking of convergent crystal lenses, he informs us that they are "useful to old men and to those whose sight is weakened, for by this means they will be able to see the letters sufficiently enlarged however small they may be." This marks the beginning of the use of spectacles to improve vision. The following quaint passage from one of his writings will give an idea of the startling effect his assertions, some of them realized only in twentieth-century achievement, must have had upon his ignorant and superstitious contemporaries:

First, by the figurations of art, there may be made instruments of navigation without men to rowe them, as great ships to brooke the sea, only with one man to steere them, and they shall sayle far more swiftly than if they were full of men; also chariots that shall move with unspeakable force, without any living creature to stirre them. Likewise, an instrument may be made to fly withall if one sit in the midst of the instrument, and doe turne an engine, by which the wings, being artificially composed, may beat the ayre after the manner of a flying bird. But physicall figurations are farre more strange; for by that may be framed perspects and looking-glasses, that one thing shall appeare to be many, as one man shall appeare to be a whole army and one sunne or moone shall seem divers. Also perspects may be so framed, that things farre off shall seem most nigh unto us.

Bacon contributed to a number of diverse fields of science. In physics, he wrote a book on optics which served as a text for two centuries. In natural history, he collected much first-hand evidence and wrote the first systematic geography, covering Europe and parts of Asia and Africa. Chemistry had not yet risen out of alchemy, but Bacon brought together what knowledge existed in this field and made many experiments, especially with gunpowder. In astronomy, he spent many years making observations and constructing tables. He advocated a corrected calendar, writing to the pope to this effect. Though the appeal was unsuccessful in his own day, the subsequent Gregorian correction may be traced to his influence. In mathematics, he familiarized himself with all that had been accomplished up to his time and applied the science very widely to practical problems. He realized its supreme importance for scientific purposes and called it "the gate and key" to the other sciences.

By far the most important of Roger Bacon's contributions, however, was his emphasis upon observation and experiment in a world still adhering quite rigidly to the written word. In teaching that mathematics is the basis of all

science, he recognized clearly that it could not take the place of direct investigation of nature and that it was useful mainly in working out general laws from observational data. He rejected the methods of his own age and stressed those of Aristotle. He insisted that all conjecture be tested by experience. Nothing is so sacred, he maintained, that it should be allowed to escape this acid test. And this in the face of St. Augustine's dictum that "nothing is to be accepted save on the authority of scripture, since greater is that authority than all powers of the human mind!"

At Roger Bacon's death his writings were suppressed, though most of them were already known to a select group of students and followers, who propagated his ideas despite ecclesiastical opposition. Nevertheless, two centuries elapse before the scientific awakening takes fuller form, for the church, becoming alarmed, increased its repressive activities, developed the dreaded inquisition, and began burning outspoken dissenters at the stake. Still the spirit of revolt would not down. The kings became almost entirely freed from ecclesiastical control; a great split occurred within the church itself (1378); independent religious orders were arising; and other events were shaping themselves, such as the utilization of gunpowder, the mariner's compass, and the printing-press, which were later to help greatly in the free spread of ideas. With the discovery of America, the rounding of the Cape of Good Hope, and the circumnavigation of the globe, the popular, church-sanctioned belief in a flat earth was shattered, and at the same time Luther defied Rome and brought on the Protestant Reformation.

§ 4

The beginning of the sixteenth century marks the passing of the Middle Ages, but the dawn of modern science is

still nearly a century away. The Reformation (1517) really retarded scientific advance for a time, since it caused the Catholic Church to tighten up still further on its proscriptions, and the Protestants were equally hostile to science. There were a number of independent thinkers during this time, but the efforts of most of them were smothered by the ecclesiastical inquisition. Their writings were either destroyed or hidden for long periods.

An example of this is seen in the work of Leonardo da Vinci (1452-1519), who was probably as versatile a genius as has ever lived. One reason why his influence was not felt more in his own generation and for hundreds of years afterward was that he wrote from right to left with the left hand. His writings had to be held up to a mirror to be deciphered. But had his views been known in his own day, the written records would probably have been destroyed as many others were.

The scope of Leonardo's researches was remarkable. It covered virtually the whole field of science, from mathematics to psychology. In mathematics, he made an extensive study of spirals and aided a noted mathematician in writing a text-book. In physics, he originated the science of hydraulics and probably invented the hydrometer; he perfected a model of a flying-machine of the helicopter type, and his analysis of the flight of birds has been unsurpassed till recent years; he designed a parabolic compass, utilizing a principle generally adopted only in the seventeenth century; he made working drawings of quick-firing and breech-loading guns; and in many other practical ways he applied mathematics and physics to the industrial arts. He invented a number of labor-saving devices, and the lock canals he built have not to this day been improved upon in principle. In astronomy, he accepted the Pythagorean theory of planetary motion. In biology, he studied the vertebrate

skeleton minutely, and his ideas about anatomy and embryology were strictly modern. He even divined the principle of the circulation of the blood, experimentally demonstrated nearly a century later by Harvey, and he clearly indicated the part the eye plays in vision. Probably most significant of all was his prophetic insight into geological truth, an insight hundreds of years ahead of the first recognized geologists. He made wide observations in meteorology, worked out in a preliminary way the effect of the moon upon the tides, correctly interpreted the meaning of fossil remains, and foreshadowed the modern hypothesis of the origin of mountains and continents. Leonardo's geological insight appears the more astonishing when viewed in the light of the misconceptions that prevailed in this field until the nineteenth century.

Leonardo da Vinci was a great scientist, but he was much more also. In his own day he was celebrated as a sculptor, architect, engineer, and painter, and he held many important public posts. His work in canal building has been touched upon. As an engineer, he served in several military campaigns and became military engineer to the infamous Cesare Borgia. As an architect, he aided in the design of the cathedral of Milan and other public buildings. As a painter, he gave to the world the celebrated "Mona Lisa" and "The Last Supper." Born at Vinci, Italy, the natural son of a Florentine notary and a peasant woman—handsome, powerful, persuasive—Leonardo stands forth as one of the most remarkable men of all time. Yet his influence on science in his own day was virtually nil.

Of the able thinkers who in the fourteenth, fifteenth, and early sixteenth centuries were courageous enough to brave ecclesiastical censorship and punishment, there was only one whose writings had an immediate effect upon scientific advance, and that was Nicolaus Copernicus (1473-1543),

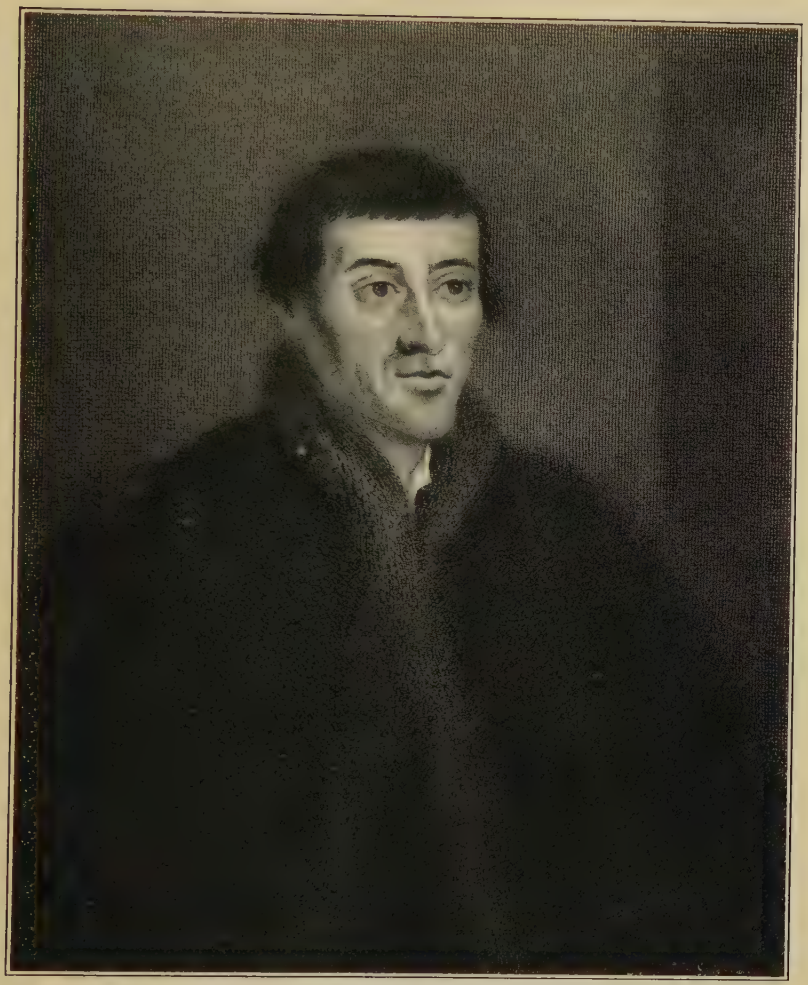
the famous astronomer. Like Leonardo, Copernicus was extraordinarily versatile. He became proficient in the classics, in mathematics and astronomy, and in medicine, law, and theology. He studied at several of the best European universities of the period, and received the degree of doctor in both arts and medicine. He was professor of mathematics for a time in an Italian university. Later he became private physician to his uncle, the bishop of Ermeland, and, upon the bishop's death, took holy orders and was ordained as canon in his home province in Poland, in which post he continued for the remainder of his life. After his ordination, his time was almost completely taken up with ecclesiastical and medical duties, but he contrived to carry on his scientific studies in odd moments. During this period, also, he was appointed by the college of canons as their representative in the State Assembly at Grodno. Here he rendered important service to his country, which at the time was engaged in a series of wars. The currency had depreciated, and Copernicus secured the passage of a stabilization law, which standardized the various kinds of money used throughout the provinces of the kingdom and placed the country on a sound monetary basis.

Copernicus's position as a scientist rests on two counts. He came out foursquare against Aristotle's cosmographical misconceptions, and he devised a system of astronomical mathematics equally complete with the famous "Syntaxis" of Ptolemy except that it was much simpler.

Copernicus possessed none of the splendid equipment used by Ptolemy and Aristarchus in Alexandria many centuries before. Yet with his slender means he managed to devise a workable method of making astronomical observations by constructing slits in the walls of his home, through which he observed the passage of the stars across the meridian. One phenomenon that struck him as peculiar was that

the brightness of Mars varies most erratically, which he could not explain under the Ptolemaic theory that the earth is the center of the universe, with Mars, among other heavenly bodies, revolving around it in a circular orbit. If Mars is always virtually equidistant from us, how could its variation in brightness be so extreme? The same variability in brilliance had been observed with respect to the other planets. Copernicus knew that the Pythagoreans had put forth a theory which placed the sun at the center of the revolving planets, with the stars stationary and the moon alone attending the earth—a theory which, if true, would account for the variations in planetary brightness, for under it the planets are at irregular distances from the earth at different times. The chief weakness of the Pythagorean hypothesis was that it had never been worked out with any degree of mathematical completeness, a task which Copernicus set for himself. The result was his epoch-making treatise, "De Revolutionibus Orbium Cœlestium." This book not only demonstrated that the Pythagorean theory could be worked out with a mathematical completeness equal to that of Ptolemy's "Syntaxis," but also that most of the complicated mathematical devices used by Ptolemy could be dispensed with.

It must be repeated, in passing, that Copernicus assumed circular courses for the planets just as Ptolemy had. He simplified the mathematics considerably, but not so completely as Kepler did a century later by substituting elliptical for circular orbits. The Copernican system was really begun by Pythagoras in ancient Greek times and completed by Kepler. Still, Copernicus did a colossal piece of work in reviving the theory in the face of ecclesiastical opposition, deeply fixed misconceptions, and common-sense impressions, and in placing it upon a secure mathematical basis. The facts as presented to the senses do seem to be against the Coper-



COPERNICUS

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nican theory. The sun appears to move across the heavens, and we still speak of it as "rising" and "setting." History usually, if not always, assigns credit where credit is due, and thus Copernicus is known by the system which bears his name and which he did so much to establish.

Had he published his treatise immediately upon its completion, Copernicus would undoubtedly have been censured or punished, for the dogmas of the church included a fixed and immovable earth. His church affiliations and allegiance made him hesitate to give offense. Furthermore, he was decidedly outspoken in his book. So he waited thirteen years before the manuscript was allowed to go to the printer, and, as fate would have it, he died a few hours after a final copy had been placed in his hands.

The treatise was immediately put under the ban, but its value soon became recognized despite this. The attitude of Copernicus toward his critics is well indicated in the following passage taken from the preface of his great work: "If there be some who, though ignorant of all mathematics, take it upon themselves to judge and dare to reprove this work, because of some passage of Scripture which they have miserably warped to their purpose, I regard them not, and even despise their rash judgment."

§ 5

We come, then, to the close of the period designated in these pages as the Dark Age of Science and the Revival. Ten centuries of scientific advance had been followed, because of man's blundering attempts to build his society upon the quicksands of brute force and exploitation, by ten centuries of darkness, broken in Europe only by the fitful gleams of the torch held aloft by Roger Bacon and passed on to a few others, by the partial revival of Greek learning, and by the addition of Hindu arithmetic and algebra to the

science of mathematics. Roger Bacon despaired at the end of his life and regretted that he had striven so hard to penetrate the darkness. He could not live four times eighty years, and so he could not witness the results of his magnificent effort. For the leaven did work finally. His attacks upon charlatanism; his emphasis on observation and experiment as against blind obedience to authority; his clear understanding of the value of mathematics in its relation to the rest of the sciences; his insistence that the earth is round and not flat—these stirrings of the scientific spirit were not lost to posterity. Two centuries later, men like Leonardo da Vinci came to carry on in one way or another, and at the same time Copernicus appeared on the scene, gathered together the scattered threads of astronomical advance, put the sun in the center of the cosmographical system, and backed up his contentions with unassailable mathematics. Under his onslaughts and those of his followers, the Aristotelian misconceptions regarding celestial and terrestrial motions crumbled, and further scientific advance was made possible. Nature's Book, though still quite tightly sealed, had again been found, whereas in the interim the Book of Man had been filled with much additional ignorant scribbling and had to await the breaking of more of the Seals of Science before intelligent erasures and more constructive insertion could be undertaken.

CHAPTER IV

THE ESTABLISHMENT OF ASTRONOMY AND THE BREAKDOWN OF AUTHORITY

§ 1

HALF a century after the death of Copernicus in 1543 and the publication of his famous astronomical treatise, there were definite signs of a breaking-away from the authority of ancient writings in several fields of scientific inquiry. But progress was still slow because of chaotic social conditions and continuing ecclesiastical opposition.

The Reformation had drawn Europe into a series of fanatical religious wars, in which massacres, hangings, ruinous taxation, forcible emigration, political intrigue, and the destruction of cities vied with one another to bring back barbarism. The results of these disastrous conflicts were the weakening of the papacy, the establishment of other religious sects equally intolerant though with considerably less power, the strengthening of royalty, the decline of Catholic Spain, the rise of France to political leadership, and the fleeting ascendancy in England of that spirit of representative government which was soon to vouchsafe her greatness. Science and art struggled along haltingly because the mind and soul of Europe were still occupied elsewhere.

By the time of the Edict of Nantes (1598) and the later Peace of Westphalia, Lutherans, Calvinists, and Anglicans had secured partial recognition from the state; and some semblance of religious freedom had become established in Sweden, Denmark, England, Holland, France, and Germany. Italy, Spain, and Austria alone, among the im-

EUROPE
1600-1650
RUSSIA
NORWAY
SWEDEN
BALTIC SEA
DENMARK
PRUSSIA
ENGLAND
CAMBRIDGE
LONDON
ATLANTIC OCEAN
NETHERLANDS
HOLLAND
BRUSSELS
WESTPHALIA
WITTENBERG
LEIPSIG
POLAND
PRAGUE
GERMANY
PARIS
TUBINGEN
AUSTRIA
LINZ
GRATZ
FRANCE
VENICE
PADUA
PISA
FLORENCE
TUSCANY
ROME
ITALY
MADRID
SPAIN
GIBRALTAR
MEDITERRANEAN SEA
GREECE
AEGEAN SEA
BLACK SEA
CASPIAN SEA
ASIA MINOR
ASIA
AFRICA

portant nations, were at this time predominantly Catholic. But what toleration had now been secured in Europe was in the main an armed truce between the various Christian sects; it did not extend beyond that point. Protestantism, though omitting some of the extreme measures still employed by Catholicism in attempting to stamp out independent thought, was just as hostile to it. The infallibility of the Scriptures had simply taken its place alongside the infallibility of the pope. Everything else was anathema, including any theory that brought into question the biblical dogmas regarding the constitution of the heavens.

Yet the continuing antagonistic attitude of both Catholicism and Protestantism toward science could not prevent the ripening of the natural fruit of the multiplication of printed books, the widening mental horizon growing out of geographical discoveries and settlement, and the substitution of gunpowder and the common soldier for sword-play and the knight errant. A spirit of curiosity and inquiry had definitely taken form, especially in the Italian peninsula, where a new and more drastic Roman inquisition was giving to that fair country the unenviable title of the Land of the Dead.

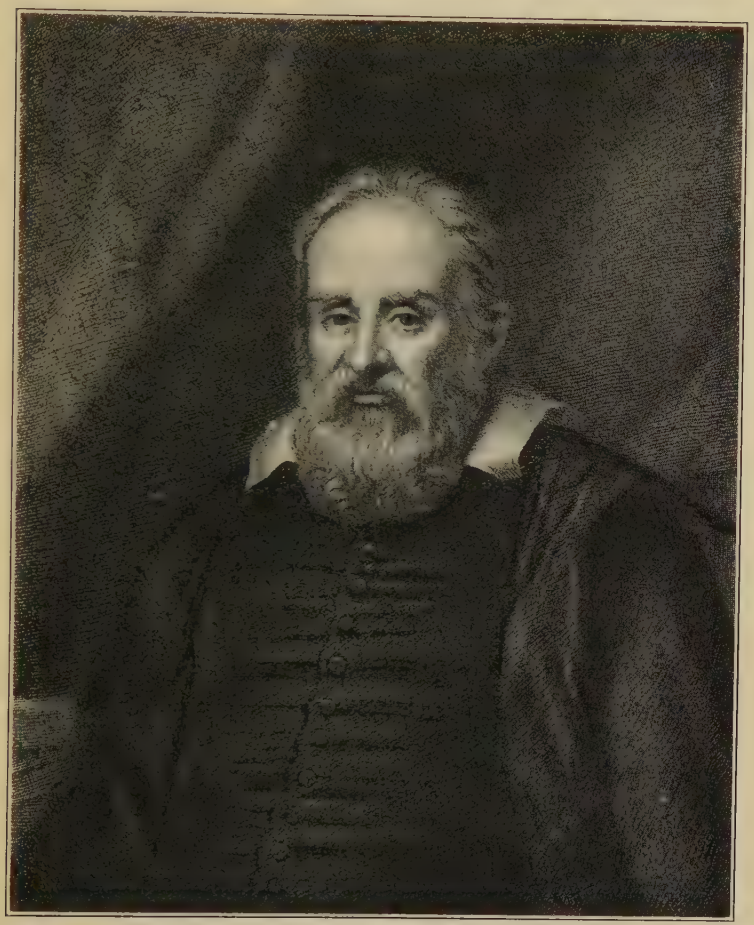
Unintelligent and brutal opposition has often served to give a renewed impetus to the movement it has endeavored to stifle, and so it happened in this instance. Italy became the battle-ground of the new astronomy which made the sun rather than the earth the center of the universe. In 1600 Rome singled out a prominent advocate of the Copernican theory, the eminent Giordano Bruno, and ordered him to recant on pain of death at the stake. Bruno refused to recant and thus went to his death; but his dying words will live forever in the hearts of men: "I yielded to none . . . in constancy, and I preferred a spirited death to a cowardly life."

§ 2

Bruno was a contemporary of other fearless thinkers who could not be crushed, either in Italy or elsewhere; among these the fiery Galileo (1564-1642) and the painstaking Kepler (1571-1630), who between them were destined to complete the destruction of the Ptolemaic-Aristotelian cosmography. The burning of Bruno at the stake served mainly, after the first hush of dread had passed, to lash the Ptolemaic-Copernican controversy into a fury, out of which the Copernican system emerged triumphant. By the time the first third of the seventeenth century had passed, the new astronomy had been definitely established.

Two outstanding achievements in the field of astronomy served to make this triumph completely possible. One was the perfection of the telescope and its use by Galileo; the other was the discovery by Kepler of the laws of planetary motion, the key-note of which was the substitution of elliptical for circular orbits as an explanation of the movement of the planets around the sun.

Galileo and Kepler were brilliant mathematicians and astronomers, they held professorships in these subjects in prominent universities, and they accepted the Copernican theory early in their careers. They were acquainted with each other, at least by correspondence; apparently secured considerable consolation in writing back and forth about their work and their troubles with ecclesiastical despotism; and fully appreciated the danger of holding unpopular views. Galileo remarked in 1597 in a letter to Kepler that he was withholding some of his arguments, for he did not desire to become, as he put it, "an object of ridicule and scorn . . . so great is the number of fools." Galileo had a sharp tongue and did not mince words on occasion.



GALILEO

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At the University of Pisa in his native city, where he received his education and where he later became a professor, Galileo brought unpopularity upon himself because of his vigorous thinking and his keen desire to get at the truth, a desire which with him amounted to a passion. His father, an impoverished Italian nobleman, had tried unsuccessfully to make a merchant out of the son, and, failing, had sent him to the university to study medicine. But Galileo was interested in pure science, and this interest could not be suppressed. Sitting in the cathedral at Pisa during a service, his attention was caught by a swinging chandelier above him. In a spirit of curiosity he timed the oscillations by his pulse-beat—for watches had not yet been invented—and noted the curious fact that, although the oscillations were dying down, the time of each swing of the chandelier remained unchanged, a discovery which formed the basis for the subsequent construction of the pendulum clock. Experimenting later with pendulums of varying length, he discovered a second important fact; namely, that the time of the swing may be made longer or shorter by changing the length of the pendulum. Combining the two discoveries, he invented the first instrument for recording the pulse-beat of a patient. During this same period of medical study, he accidentally overheard lessons in Euclid being given at the home of a friend and induced the tutor to give him lessons also. Soon, the study of medicine forgotten, he was deep in mathematics and physics, mastering the writings of Archimedes and making scientific suggestions which brought him to the attention of the premier mathematician of Italy, who secured for him the chair of mathematics at Pisa.

Here, at the very beginning of his career, Galileo performed his famous experiment of dropping a light and heavy ball of metal from the top of the leaning tower of Pisa to disprove Aristotle's contention that a heavy body

falls faster than a light one. Aristotle's is the common-sense assumption, for it is in every one's experience that a piece of paper flutters to the ground more slowly than a stone drops. Yet the difference is due only to the resistance of the air, and when this is eliminated the paper and stone fall with the same speed, as experiments *in vacuo* amply demonstrate.

In his experiment, Galileo used a hundred-pound cannon-ball and a half-pound weight, the compactness of the objects rendering the resistance of the air negligible. He released them together. But as the cannon-ball and the weight struck the ground simultaneously before the astonished eyes of the antagonistic crowd that had gathered, only angry mutterings arose. Galileo was called a sorcerer and magician, for not only did the result violate common-sense impressions but the great Aristotle had taught the very opposite. And what Aristotle taught was not to be questioned. So, his colleagues reasoned, Galileo must have resorted to witchcraft! The leaning-tower-of-Pisa experiment was but an illustration of how in one way or another Galileo thundered forth his anathemas against the blind antiquity worship of the day, until his enemies in Pisa forced him to give up his professorship. Luckily, however, his fame had spread, and in 1592, still less than thirty years of age, he was invited to go to the University of Padua, where he continued his experiments, though he curbed his utterances somewhat until after his reëlection in 1598.

Then came the martyrdom of Bruno, and Galileo determined to take up the challenge. He watched his opportunity and found it in the appearance of a new and brilliant star in 1604. Here was an object-lesson. How account for a strange star in the never-changing, immutable heavens of the Aristotelians? He unleashed his bitter

tongue again. Before large audiences he flayed his enemies and for the first time came out boldly for the Copernican system. Soon he was the storm-center of the controversy, with the clerics watching his every move. But Padua was tolerant in regard to religion, and so long as Galileo stayed there he was safe from actual persecution.

It was at this period that he received word from Holland of a crude magnifying contrivance, which his inventive genius seized and perfected into the telescope. His first improvement enabled him to see objects three times as large and nine times as near. He quickly followed this with another instrument which magnified objects about thirtyfold and brought them many times nearer. This he pointed toward the heavens with further devastating results upon the Aristotelian cosmography. Again his trenchant pen and sharp tongue flayed the opposition. "Where is your perfect moon," he shouted, "when through my telescope it shows itself all scarred and indented?" "Why assume the earth to be the center of the universe," he continued, "when I see four bodies circling around the planet Jupiter?" His opponents were beside themselves. One prominent critic insisted that since the moons of Jupiter could not be seen with the naked eye, they did not exist. Another simply refused to look through the "devil's glass."

"Oh, my dear Kepler," writes Galileo, "how I wish we could have one hearty laugh together! Here, at Padua, is the principal professor of philosophy, whom I have repeatedly and urgently requested to look at the moon and the planets through my glass, which he pertinaciously refuses to do. Why are you not here? What shouts of laughter we should have at this glorious folly! And to hear the professor of philosophy at Pisa laboring before the grand duke with logical arguments, as if with magical incantations to charm the new planets out of the sky."

With his telescope, Galileo continued to "push back the heavens" and add to his fame. He discovered a sun-spot and by watching its changing positions calculated that the sun revolves on its axis every twenty-four days. He resolved the Milky Way into myriads of tiny stars. He discovered the rings of Saturn. And in many other ways he opened up the heavens as they had never appeared before.

Galileo had become by this time the idol of the Venetian Republic, under whose tolerant protection he should probably have remained. But he had long desired to be back in his home in Tuscany, despite its bigotry and intolerance and the nearness of Rome, and so in 1610 he returned, receiving an appointment in Florence, where he continued his researches in physics and astronomy and his criticism of the Aristotelians. The ecclesiastics now saw their opportunity and began stirring up Rome, until finally Galileo was sent for in 1616, his works were put under the ban, and he was enjoined on pain of torture and imprisonment to cease his "heretical opinion." Under duress, he promised never to teach the Copernican doctrine again, and by this forced promise he abode impatiently for fourteen long years.

In the meantime, Galileo's friend Kepler was busily engaged in Germany destroying the Ptolemaic system, if not in as spectacular a manner, yet in a way which struck at its very roots. Kepler had had troubles of his own. Born in an atmosphere of poverty and domestic bickering, sickly as a child and with his eyesight almost ruined because of a serious illness, he began life with many handicaps. But he possessed a dogged perseverance and a genius for mathematics which soon won him a number of influential friends. These aided him in getting to the University of Tübingen, which he entered at the age of seventeen. Here he soon distinguished himself under the professor of mathematics, Michael Maestlin, who was an ardent supporter of

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Photo: Mount Wilson Observatory.

THE SURFACE OF THE MOON
(as revealed by the "devil's glass")

Copernicus, and who deeply influenced young Kepler. At twenty-three, Kepler was already installed as professor of mathematics at the University of Gratz.

Here he began to speculate about the general plan of the solar system. He knew that there were glaring discrepancies between the circular orbit theory of planetary motion and the observed facts, and he was aware that the six planets then known—Mercury, Venus, the earth, Mars, Jupiter, and Saturn—move in their courses at variable speeds and that the farther a planet is from the sun the more slowly it moves. The way Kepler went about his problem is highly illuminating. Questioning the theory of circular orbits, he tried every conceivable movement he knew anything about, triangular, pentagonal, hexagonal, and so on, in each instance testing his hypothesis with the observed facts and discarding the hypothesis when he found it did not fit.

At first, however, Kepler did not have very accurate data to go by. When his earlier theories were put forth in 1596, he thought the results accorded fairly well with the facts, but they did not. Their publication served mainly to put him in close touch with Galileo, in then far-off Italy, and to bring him an invitation from the greatest astronomical observer of the age, Tycho Brahe, to come to Prague, in Bohemia, and test his hypotheses with the observations there recorded. Kepler accepted the invitation, went to Prague and tested his theories, found they did not accord with Brahe's observations, and unhesitatingly discarded them.

This visit won for Kepler the friendship and admiration of Brahe, with the result that he received an offer to work with him under the patronage of King Rudolph of Bohemia. Here was an unusual combination, a great mathematician working hand in hand with a great observer. To be sure,

soon after Kepler's arrival from Gratz Brahe died, but his wonderfully accurate observations on planetary motion were at Kepler's disposal. Furthermore, as the result of a promise made to Brahe before the latter's death, Kepler himself completed a series of observations that the two had begun together and published them after considerable difficulty a number of years later under the title of the Rudolphine Tables, in honor of King Rudolph, who had also died in the interim. These tables were of the utmost importance and for hundreds of years served navigators much as the Nautical Almanac of England serves to-day.

Long before the publication of the tables, Kepler had begun to correspond with Galileo, both with respect to the Copernican theory and the construction of magnifying instruments. While Galileo was confounding the ecclesiastics of Italy by breaking through the heavens with his telescope, Kepler was struggling along in a new position at the University of Lenz, in Austria, where he had gone after the death of King Rudolph, worries besetting him on every hand. Being short of funds, he had begun publishing an almanac, through which he practised astrology, as was done even by Galileo and also by other noted men of that period, not to mention the motley crowd who knew nothing whatever of the movements of the heavenly bodies but practised charlatanry pure and simple.

Kepler's family had been very ill and had almost starved; his salary was in arrears; his mother had been accused of sorcery and had escaped torture only because of his personal intercession; and his efforts to raise money to have the Rudolphine Tables published were meeting with little success. He was hardly in the mood to indulge in laughter at the time his friend Galileo wrote him wishing the two could be together.

Yet, through all his troubles, Kepler continued doggedly

with his speculations as to planetary motion. His earlier theories discarded, he tried others, only to reject these in turn as not according with the facts, until at last he hit upon elliptical orbits with the sun at one of the foci, and, lo and behold, the hypothesis worked! We can well imagine his joy when he applied Brahe's observations and found that they accorded precisely with this final theory.

Kepler's great revelation that the planets move in elliptical orbits about the sun paved the way for his second discovery. He had been perplexed, also, by the variations in the rate at which they move. Observations showed that they change position at variable speeds, traveling more slowly at certain times than at others. When near the sun they move fastest; when far away, slowest. Applying the trial-and-error method to this problem, he finally discovered the curious fact that the observed variations in speed are such that planets sweep over equal areas in equal times—which is to say that, if an imaginary line is drawn from the sun to a planet moving in its elliptical path, and one end of the line is considered as fixed at the sun while the other end moves with the planet, the quasi-triangular areas swept over by the line in like periods of time are always the same.

Kepler published his first two laws in 1609 in his book on the motions of Mars, at the time Galileo was at the height of his fame in Padua. But Kepler was not yet satisfied. Still another problem was puzzling him, and this related to the periods of the planets; that is, the lengths of time they take to complete their orbital paths. These periods, it had long been observed, are not the same for the different planets. The greater the average or mean distance of a planet from the sun the longer does it take to complete its orbit. Was there any exact relationship, Kepler now asked himself, between the average distances of the planets from the sun and their respective periods?

Again he experimented mathematically. Once more he tried various combinations. He squared the periodic times and the mean distances, he cubed them, he raised them to higher powers—all the while making comparisons to establish a possible relationship. And finally, for a third time, he hit upon a great truth. He discovered that there is an unvarying ratio between these two factors; namely, the squares of the periodic times, t, are as the cubes of the mean distances, r. In other words $\frac{r^3}{t^2}$ is a constant, or $r^3 = kt^2$.

Kepler published his third law in 1619, writing of it: "That for which I joined with Tycho Brahe, for which I settled in Prague, and for which I have devoted the best part of my life to astronomical contemplations, this at length I have brought to light. It is not eighteen months since the first glimpse of light reached me, three months since the dawn, very few days since the unveiled sun, most admirable to gaze upon, burst out upon me. Nothing holds me; I will indulge in my sacred fury; I will triumph over mankind by the honest confession that I have stolen the golden vases of the Egyptians to build up a tabernacle for my God, far away from the confines of Egypt. If you forgive me, I rejoice; if you are angry, I can bear it; the die is cast; the book is written; to be read either now or by posterity, I care not which; it may well wait a century for a reader, as God has waited six thousand years for an observer."

In writing as he did, Kepler realized full well that the ban of the church would fall upon his revelations; for, three years before, the College of Cardinals had suppressed his other publications with those of Copernicus and Galileo. But the arm of the church could not reach Kepler in Austria as easily as it could Galileo in Italy, and so his person was

safe. How he regarded his critics is well summed up in what he wrote on a previous occasion:

> If any one be too dull to comprehend the science of astronomy, or too foolish to believe in Copernicus without prejudice to his piety, my advice to him is, that he should quit the astronomical school, and condemning, if he will, any or all the theories of philosophers, look to his own affairs, and leaving this worldly travail, go home and plow his fields.

Kepler's contributions to astronomy were indeed great. The discovery of any one of his three laws would have been sufficient to give him lasting fame; and he did not stop there. In the course of bringing the Rudolphine Tables to completion (they were not published till 1627), he incorporated his new discoveries and set down the observed facts regarding the planets in such manner that their locations could be easily computed far in advance. In addition, he came nearer to estimating the true distance of the earth from the sun than any astronomer since Hipparchus; he made a profound study of comets, his explanation of the reason why their tails point away from the sun being almost identical with that which is accepted to-day; and the prodigious amount of tedious computing he did, without logarithms or modern tabulating devices, is almost beyond comprehension. The invention of logarithms by his contemporary Napier, though coming too late to aid him very much, was hailed enthusiastically by Kepler, who exclaimed that it would triple the life of the astronomer.

It is difficult for us to conceive how startling the discoveries of Kepler must have been in his own day. That planets move in circular paths was a deeply rooted belief, handed down from the ancient Greeks and accepted unquestioningly even by Copernicus. An elliptical orbit was a

revolutionary idea to Galileo, who was quick to accept it, however, and make use of it in his lectures against the Ptolemaic system, so soon as his friend had set forth his proofs. Kepler's other discoveries were equally startling though more difficult to visualize.

Kepler died in 1630, soon after the publication of the Rudolphine Tables. The same year, after a long period of enforced silence, Galileo published his great work on the Ptolemaic and Copernican systems, written in dialogue to conform with the spirit of his promise to the ecclesiastical authorities. The book immediately created a tremendous stir; and, although it was later suppressed and Galileo was forced to recant to save his aging body from torture and for a few more years of research, the mischief had been done. The new knowledge spread throughout Europe. The demolition of the Aristotelian cosmography was complete. Between them, Kepler and Galileo had placed astronomy on a secure scientific basis, from which it could proceed to perfect its principles. The second Seal of Science had finally been broken.

§ 3

It was not only the established view of the universe that was crumbling during this period. The authority of Aristotle in other fields was likewise being swept aside. Kepler and Galileo did not stand alone. Contemporary with them, Gilbert in physics and Harvey in biology were shattering the ancient traditions.

Galileo, as has been noted, was disconcerting the Aristotelians not merely in the field of astronomy but in that of physics as well. Both he and Kepler advanced the study of optics. Kepler worked out the principles underlying the refraction of light through various media, such as air and glass, to the stage from which the laws of refraction were

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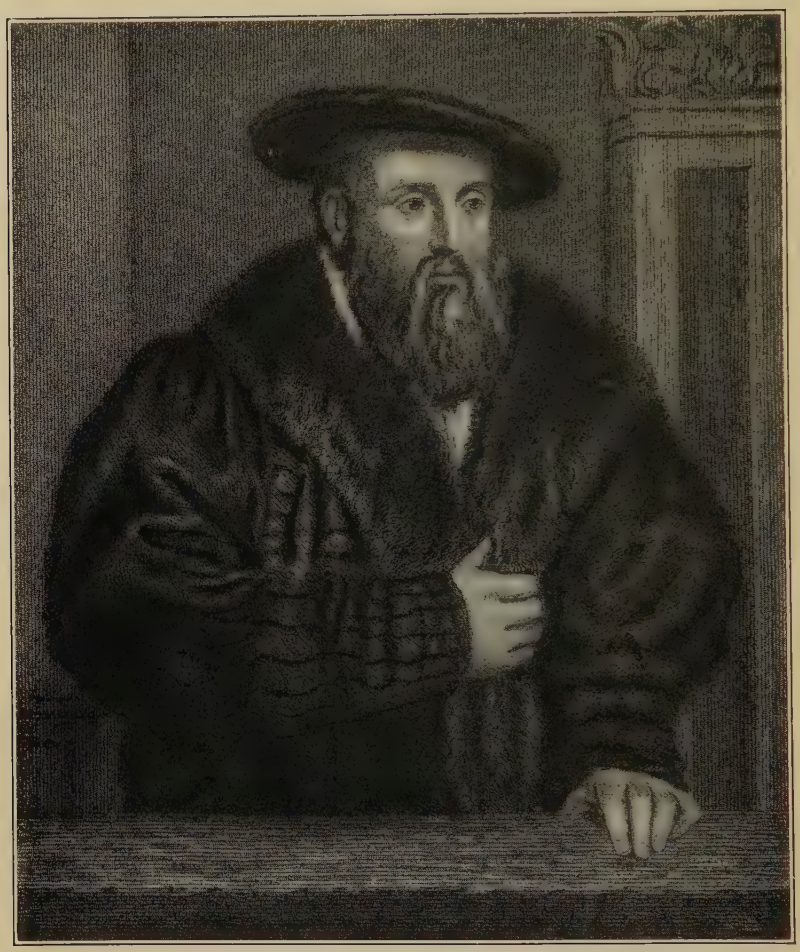

KEPLER

later derived, while Galileo, in addition to perfecting the telescope, discovered many of the important principles underlying the use of lenses. He also invented what was probably the first thermometer and began the quantitative study of heat.

In dynamics, a most important department of physics, Galileo's contributions equaled in importance his work in astronomy. Following his famous experiment with heavy and light weights dropped from the leaning tower of Pisa, which so antagonized his colleagues and others that he was forced to give up his professorship at the university there, Galileo worked out the laws of falling bodies now familiar to every school-boy. He noticed that a body dropping to earth does not descend at a uniform speed but that its velocity increases as it falls. So he determined to find a definite mathematical relationship, with respect to falling bodies, between time, speed, and distance, just as Kepler had faced the problem of the relationship between planetary orbits, distances, and periods. Galileo performed a number of interesting experiments with balls rolling down inclined planes, taking care to minimize the effects of friction and constructing an ingenious yet simple timing device. After collecting sufficient data, he applied his mathematics and found that the observed increase in velocity when a body falls is directly proportional to the time of falling; that is, the ratio of the velocity, v, to the time, t, is a constant, $\frac{v}{t} = k_1$ or $v = k_1 t$. From this he derived as a corollary that distance of fall, d, varies as the square of the time, that is, $d = k_1 t.^2$ The constant here is different from the one applying to Kepler's formula and is thus indicated as k_1.

As in the case of Kepler's laws, Galileo did not explain *why* these ratios must exist. He merely stated the facts. It took a still greater genius in the next generation to ex-

plain both Kepler's and Galileo's discoveries. The significant point is that Galileo's work in dynamics swept aside the misconceptions of Aristotle regarding falling bodies and laid a secure foundation upon which future scientists could build. Galileo also established mathematically that the path of a projectile, which gunners had long since recognized as deviating from a straight line, is a parabolic curve, and that there is a direct inverse relationship between weight and distance when bodies are acted upon by a given force; for example, a force that will move a two-pound weight through one foot of distance will move a one-pound weight exactly two feet, or a half-pound weight exactly four feet.

In concluding this brief sketch of the most important of Galileo's contributions to physics, it is fitting to recall that, when at the age of sixty-nine he saved his body from the torture-rack and the flames to which an ecclesiastical despotism stood ready to consign him unless he recanted with respect to his astronomical beliefs, he was undoubtedly preserving himself for the uncompleted work on dynamics he had begun more than forty years before at Pisa. It was during these last years that he finished his experiments. Under the watchful eyes of the clerics, a virtual prisoner, and with failing health, the great Galileo had passed seventy when he prepared to hurl his last thunderbolt into the ranks of bigotry and authority. Under tremendous handicaps, he published in 1636 the now famous "Dialogues on Motion." The devastating effect of this great work on preconceived ideas was not appreciated at once by the clerics, but it apparently had struck home by the time Galileo died six years later, for he was denied decent burial, all his manuscripts were seized and some of them burned, and even his will was vigilantly scrutinized and disputed.

Happily, Galileo's older contemporary in physical ad-

vance, William Gilbert (1544-1603), was born in England and not under the eyes of Rome. For England in Gilbert's day had become quite tolerant as compared with the England of Roger Bacon's day. Gilbert thus escaped persecution, although his researches in electricity and magnetism met with the same type of bigoted opposition as did Galileo's in dynamics. How the first great man of science in England since Roger Bacon regarded his opponents is well expressed in the preface to his monumental work, "De Magnete," published during the year of Bruno's martyrdom in 1600:

> Why should I submit this noble science and this new philosophy to the judgment of men who have taken oath to follow the opinions of others, to the most senseless corrupters of the arts, to lettered clowns, grammatists, sophists, spouters, and the wrong headed rabble, to be denounced, torn to tatters, and heaped with contumely! To you alone, true philosophers, ingenuous minds, who not only in books but in things themselves look for knowledge, have I dedicated these foundations of magnetic science.

How this bold stand for observation and experiment must have rankled in the minds of the guardians and protectors of the written word!

Gilbert was educated at St. John's College, Cambridge, specializing first in mathematics and later in medicine. He received the degree of M.D. in 1569 at the age of twenty-five. Following the custom of educated Englishmen of the day, he now spent a few years in travel on the Continent, visiting Italy, then the intellectual center of the world despite the religious intolerance of Rome. He settled down in London to practise medicine in 1573, and soon established a wide reputation both as a physician and as an experimentalist along chemical, electrical, and magnetic lines, his home becoming the rendezvous for a group of admirers and

followers who watched his experiments and accepted his conclusions. His fame reached its height during the year the "De Magnete" was published, in 1600, when he became president of the Royal College of Physicians and chief physician to the court of Queen Elizabeth. He died three years later.

Gilbert discovered some of the basic facts of electrical science. He put forth the conception that the earth is a giant magnet and invented the term "pole" to explain certain of the observed facts. He was the first to distinguish between substances that can be electrified by friction and those that can not.

Great as were Gilbert's discoveries his greatest service undoubtedly lay in clearing away some of the weeds of misconception which had grown up about the subjects of electricity and magnetism since ancient days, and which constituted a part of the Aristotelian dogmas of Gilbert's period. This service was the more valuable, since alchemy, astrology, and magic were all involved in the false ideas Gilbert attacked; and, until they were cleared away, little progress in chemistry as well as in electricity and magnetism could be expected.

The phenomena of magnetism had long been mixed up with magical practices. As Gilbert says, "The lodestone was accused of producing melancholy, of making love philters, of losing its power when rubbed with garlic, and regaining it when smeared with goat's blood, of declining to attract iron in the presence of diamond." Applying the test of rigid experiment to each of these conceptions in turn, Gilbert demonstrated them to be baseless. It had been taught that a piece of iron rubbed with a diamond becomes magnetized. As Gilbert says further: "We made the experiment ourselves with seventy-five diamonds in presence of many witnesses, employing a number of iron bars and pieces of

HARVEY

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wire, manipulating them with the greatest care while they floated in water, supported by corks; but never was it granted me to see the effect mentioned." It had been held for two thousand years that amber alone can be excited by friction to attract other bodies. Gilbert dispelled this notion and demonstrated that many substances can be thus excited, among them glass, sulphur, and resin. It had been known for thousands of years that a compass-needle always points in a certain direction, and many had been the speculations advanced to explain this phenomenon. Gilbert's discovery that the earth is a magnet, with "poles" at the north and south, furnished a simple explanation of both compass direction and dip.

Gilbert cleared away much of the underbrush, and in doing so emphasized anew the value of observation and experiment as the basis of scientific investigation. It would be going too far afield to indicate the innumerable ways in which the "De Magnete" laid the foundation for a better understanding of scientific truth. It is a good book to dip into. It contains many quaint and humorous as well as illuminating passages. When Galileo had seen it, he expressed his opinion about Gilbert enthusiastically: "I think him worthy of the greatest praise for the many new and true observations which he has made, to the disgrace of so many vain and fabling authors, who write not from their own knowledge only, but repeat everything they hear from the foolish and vulgar, without attempting to satisfy themselves of the same by experiment."

§ 4

While Gilbert was at the height of his fame in London, a young contemporary, destined to strike at the citadel of authority from another quarter—also an Englishman and also interested in medicine as a career—had journeyed to

Padua to complete his medical training under the renowned surgeon and anatomist Fabricius. This was William Harvey (1578-1657), the celebrated discoverer of the circulation of the blood. Like Gilbert, Harvey became prominent as a physician in London and served royalty, as physician first to James I and later to Charles I. Harvey's contributions to scientific advance were, as already suggested, in the field of biology.

Again, the important influence here was in breaking down the bars of unquestioned authority. In this respect Harvey was considerably aided by the work of two eminent predecessors, Valerius Cordus (1515-1544) and Andreas Vesalius (1515-1564), one a German and the other a Belgian.

Cordus was a botanist and the son of a botanist. In his day the relation of botany to medical practice was intimate, since in the healing art herbs and plant products were utilized very extensively. Every physician was a botanist and every botanist a physician. It will be remembered that Dioscorides in the first century had written a medical botany, which because of its practical aspects had come to overshadow the earlier and better work of Theophrastus. By the fifteenth century Dioscorides was giving place to Theophrastus, and with the coming of the youthful genius Cordus (who did all his work before he was twenty-nine), the still further step was taken of describing plants anew from nature instead of placing full dependence on the incomplete descriptions of the ancients. Cordus lectured at Wittenberg, in Germany, where he taught men to break away from the past and think for themselves. He wrote a notable work on plants, was an excellent first-hand observer, and explored the botanical riches of Germany to good effect. In 1542 he visited Italy on a botanical expedition and died prematurely in Rome before his work was completed. He

left his imprint on botanical advance in both Germany and Italy.

Vesalius, the other important predecessor of Harvey, was born at Brussels and received his medical education at the best known universities of France and Italy. He had a distinguished public career as a physician, serving as army surgeon in Flanders, then as professor of surgery at Padua and other universities, later as court physician to Charles V, and still later as court physician to Philip II at Madrid. He made a pilgrimage to Jerusalem in 1563 and died on the return voyage.

The great work of Vesalius lay in the biological field of anatomy. His writings on the structure of the human body have been likened by a noted historian to the discovery of a new world. Vesalius broke away from Galen, who had held undisputed sway for fourteen centuries, and attempted to place anatomy on the firm basis of exact observation. In differing from Galen and in indicating his disgust with the crude dissections of his day, he incurred the enmity of many of his fellow-physicians, but at the same time he gathered a number of followers to himself who faithfully carried forward his ideas.

It was the influence of Vesalius which Harvey felt on arriving at Padua half a century later. Vesalius had broken with the Galenic tradition in anatomy. Harvey set himself the task of doing the same for physiology. He was not satisfied with Galen's ideas about bodily functions. In fact, no rational understanding of the dynamics of the human system was possible so long as one accepted the conclusions of the Galenic school that the arteries are filled with air. This false notion arose because they are found empty after death.

During the early part of his medical practice in London, Harvey was appointed in 1615 as lecturer on anatomy at the College of Physicians. Here he commenced his carefully

planned and ingeniously executed experiments which led to the discovery that the blood actually flows in a circle from the heart through the arteries and veins back to the heart again. He began teaching this doctrine in 1619 and immediately aroused a storm of opposition from the medical fraternity. The storm raged for twenty-five years before the truth of his discovery was recognized, and in the meantime (in 1628) he published a tract on the subject which fortified his contentions with the most solid and convincing proofs. His own statement regarding his discovery, made in this tract, is of considerable interest:

> I frequently and seriously bethought me, and long revolved in my mind, what might be the quantity of blood which was transmitted, in how short a time its passage might be effected, and the like; and not finding it possible that this could be supplied by the juices of the ingested aliment without the veins on the one hand becoming drained, and the arteries on the other hand getting ruptured through the excessive charge of blood, unless the blood should somehow find its way from the arteries into the veins, and so return to the right side of the heart; I began to think whether there might not be a motion, as it were, in a circle. Now this I afterwards found to be true; and I finally saw that the blood, forced by the action of the left ventricle into the arteries, was distributed to the body at large and its several parts, in the same manner as it is sent through the lungs, impelled by the right ventricle into the pulmonary artery, and that it then passed through the veins and along the vena cava, and so round to the left ventricle in the manner already indicated. Which motion we may be allowed to call circular.

Besides his famous discovery, Harvey's main contributions to science lay in breaking away from the ancients in other important respects and in emphasizing the need for first-hand observation and experiment.

With Cordus, Vesalius, and Harvey, three important branches of biological study (botany, zoölogical anatomy,

and zoölogical physiology) became freed from the thraldom of authority, and the ground was made ready for a further advance. Yet many misconceptions were still rife, and others were to follow. In the field of biology and elsewhere, as will be seen more fully later, new fallacies came to be accepted as fast as the old ones were swept away, for the reason that the sciences preceding them in the hierarchy had not yet been established. Other great scientists were still to come and establish physics as securely as Kepler and Galileo had established astronomy and the ancient Greeks mathematics. Until then, chemistry, geology, biology, and psychology were forced to mark time. As yet only the first two Seals of Science had been broken.

§ 5

The significant thing about the period here under consideration (the first third of the seventeenth century) is that, in addition to the establishment of astronomy as a science, the blind acceptance of Aristotle's results (whether true or false) had come to an end, and his inductive methods, a return to which Roger Bacon three and one half centuries before had pleaded for in vain, were finally being revived. The critical angle from which Aristotle has been viewed in the last two chapters should not obscure his great contributions. It was the impossibility of separating the true from the false in his writings, since the blind adherence to the written word compelled the acceptance of the false with the true, which fettered progress. The bonds had now been severed by a return to direct observation and experiment. The scientific renaissance had dawned. It was already well under way when Galileo published his "Dialogues on Motion" in 1636.

CHAPTER V

THE SCIENTIFIC RENAISSANCE

§ 1

As the authority of the ancients had now been renounced, new hypotheses to account for nature's mysteries were put forth in many quarters. Science underwent a virtual rebirth, and its various branches developed in an unprecedented fashion. The new spirit of inquiry, so relentlessly pursued by Galileo, saw fruitful expression in all scientific fields after his death. Yet even in his own day, in addition to the early seventeenth-century pioneers whose works have just been reviewed, two other outstanding spokesmen of the modern era, Francis Bacon (1561-1626) in England and René Descartes (1596-1650) on the Continent, were contributing in unique ways to the reawakening.

That scientific thinkers like Galileo, Kepler, Gilbert, and Harvey should break away from adherence to the written word was not enough. The popular imagination had to be stirred to a realization of the meaning and value of science before the scientific awakening was complete. Bacon and Descartes, each emphasizing different phases of scientific method—phases, in fact, that to many seem diametrically opposed—caught the popular fancy and carried it with them. Francis Bacon put exclusive emphasis upon the inductive approach; that is, upon direct observation of nature and inferences drawn therefrom, as against deductions from the written words of the past. René Descartes emphasized new theories and new deductions as against the old. Each in

his own way created a sensation and drew able thinkers in great numbers to the sciences.

Apparently unrelated to his illustrious namesake Roger, who lived three and a half centuries earlier, Francis Bacon was a man of many contradictions. He has stirred up more controversy about himself than any other scientific writer in history. To-day his personal character is both vehemently assailed and defended. He is thought by some to have written the plays of Shakspere, while others treat the suggestion as preposterous. Some authorities consider him the originator, as he himself claimed, of a new inductive method. Other equally reliable authorities insist that he added nothing whatsoever to the methods of scientific induction laid down by Aristotle. Be the virtues of these various claims and counter-claims what they may—we cannot assess them here—there is one thing certain: Francis Bacon had a remarkably trenchant pen and a matchless facility of expression, and he carried the popular imagination with him in his emphasis upon observation and experiment as against blind adherence to the written word. The following passage accredited to him, although its authorship is in considerable doubt, illustrates admirably the irony and sarcasm he could muster to emphasize his contentions:

In the year of our Lord 1432, there arose a grievous quarrel among the brethren over the number of teeth in the mouth of a horse. For thirteen days the disputation raged without ceasing. All the ancient books and chronicles were fetched out, and wonderful and ponderous erudition, such as was never before heard of in this region, was made manifest. At the beginning of the fourteenth day, a youthful friar of goodly bearing asked his learned superiors for permission to add a word and straightway, to the wonderment of the disputants whose deep wisdom he sore vexed, he beseeched them to unbend in a manner coarse and unheard of, and to look in the open mouth of a horse and find answer to their questionings. At this, their dignity

being grievously hurt, they waxed exceedingly wroth; and, joining in a mighty uproar, they flew upon him and smote him hip and thigh, and cast him out forthwith. For, said they, surely Satan hath tempted this bold neophyte to declare unholy and unheard of ways of finding truth contrary to all the teachings of the fathers. After many days more of grievous strife the dove of peace sat on the assembly, and they as one man, declaring the problem to be an everlasting mystery because of a grievous dearth of historical and theological evidence thereof, so ordered the same writ down.

Born into the turbulent nobility of Elizabethan England, the England of Gilbert, Harvey, and Shakspere, son of the lord chancellor and nephew of the lord treasurer, Francis Bacon became acquainted very early with the Machiavellian intrigues of the court life of his day. Precocious as a child and inheriting both intellectual brilliance and courtly self-confidence, he soon conceived of himself as destined to improve man's reasoning faculties; and to this conception he held fast throughout his career, despite the ignominy into which his scheming drew him. By the time he was fifteen he had already completed a two years' course of study at Trinity College, Cambridge. He then went to Paris, where he spent three years as clerk in the office of the English embassy. At eighteen he returned to London, the city of his birth, to study law. From law he stepped into politics, where he became engaged in one intrigue after another in his efforts to gain influential political recognition. At first these efforts were unsuccessful, but he eventually secured the post of attorney-general, after which he was made lord keeper of the great seal and finally lord high chancellor of England. As lord chancellor he was the foremost judge of the land and a prominent member of the privy council.

Bacon's intrigues brought him not only political preferment. They also brought him political ruin. In 1621, at the

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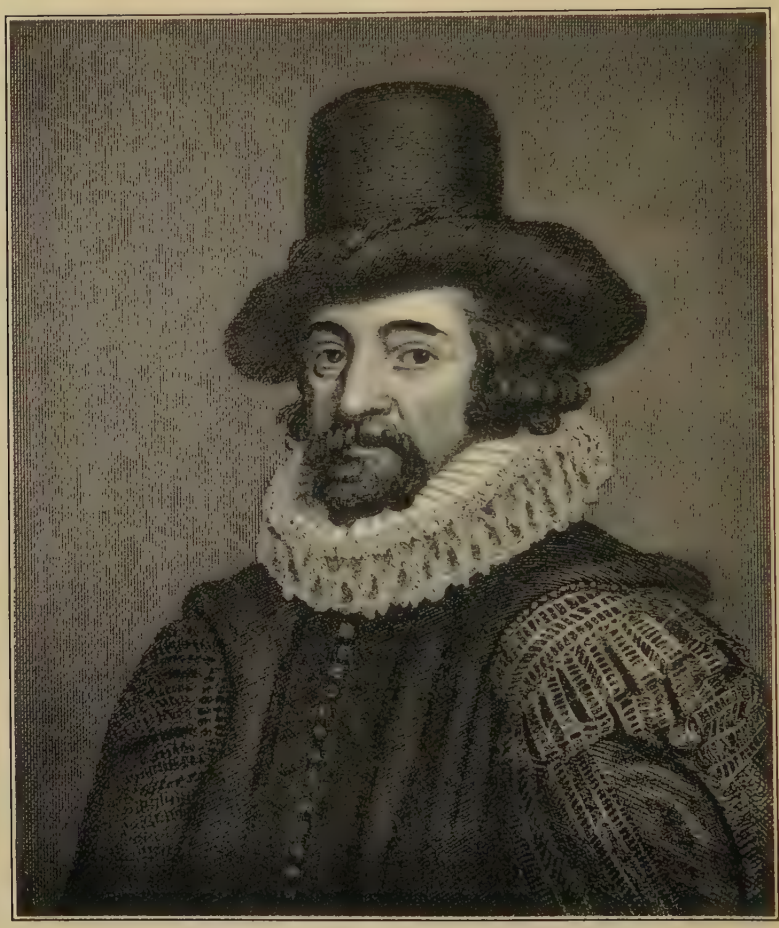

FRANCIS BACON

height of his public success, he was tried and convicted in the House of Lords on charges of bribery and corruption which he could not deny. He was sentenced to life imprisonment and ordered to pay a fine of about two hundred thousand dollars. Although pardoned by the king, Bacon's public activities ended in disgrace, and he retired to his literary occupations. In respect to these, however, he has already become known through several publications of scientific interest, especially through the "Novum Organum," which sets forth his views on the scientific method as well as on other subjects. Before drawing the curtain on Bacon's unhappy public career, it should be noted that he had been led, as a youth, to believe the key to worldly success lay in intrigue and double-dealing, and that he consistently regarded his worldly occupations merely as a means to an end; namely, to provide himself with the leisure and income to pursue his literary work to best advantage.

Few have been greater than Francis Bacon in literary achievement. "He is historian, essayist, logician, legal writer, philosophic speculator, writer on science," all in one. Yet in these things, as apparently in everything else, he is a paradox. Although he despised the English language and strove to write chiefly in Latin, it is as a great master of English prose that he is remembered. His intuition, his speculative power, his imaginative insight, have rarely been surpassed, and yet he discountenanced these faculties; it was the value of observation, experiment, and carefully drawn inductions upon which he laid exclusive emphasis in his scientific and philosophic writings. He strove to establish a trustworthy system for gathering scientific truth, and yet he often guessed at facts in a most unscientific way and failed to keep up with the accomplishments of his own generation. He apparently knew nothing

of the advances being made by Harvey, Gilbert, Kepler, and Galileo. His influence was nevertheless tremendous and his work of the greatest importance.

How Francis Bacon, in emphasizing the meaning and need of observation and experiment in the search for truth, ridiculed the ecclesiastics and scholastics of his day has been indicated in the anecdote regarding the number of teeth in the mouth of a horse. Whether or not he actually wrote the passage, no better illustration of his attitude toward their methods could be given. In another place he caustically says of them:

> Having sharp and strong wits, and abundance of leisure, and small variety of reading, but their wits being shut up in the cells of a few authors (chiefly Aristotle their dictator), as their persons were shut up in the cells of monasteries and colleges, and knowing little history, either of nature or of time, they did out of no great quantity of matter and infinite agitation of wit spin out unto us those laborious webs of learning which are extant in their books.

On the constructive side, his facile pen described in many ways how scientific endeavor should be organized. The most charming of his sketches along these lines is the "New Atlantis," in which he pictures an imaginary island, discovered accidentally by a group of sailors lost at sea, on which there was a great temple of learning, a college of science, through which all knowledge was being made manifest. In this temple there were deep caves for carrying on experiments in refrigeration, high turrets for making meteorological observations, a chamber of health for conducting studies in disease, gardens for carrying out experiments in horticulture, operating-rooms for vivisection on beasts and birds, perspective-houses for the study of optics, and finally an establishment for investigating illusions, magical tricks, spirit manifestations, and the like. This temple of learning was controlled by a group of fellows chosen

because of merit. They were of differing rank, each rank exercising different functions. Some traveled and collected material, others compiled knowledge from books, others experimented in the laboratories, others applied theoretical discoveries to practical ends.

Bacon's imaginative temple of learning was fanciful in his own day, yet we have only to look about us now to see his dream come true. Virtually every detail of his "New Atlantis" speculation has become a reality. He urged, among other things, that a nation cannot be truly great unless it set aside some of its material resources for the endowment of research and exploration. His powerful appeals stimulated public interest and spurred the establishment of learned societies and academies all over Europe.

Francis Bacon gained for science the receptive ear of the general public of England, from which country his influence extended itself to the rest of the world. Eighteen years after his sudden death in 1626 (which occurred as the result of an experiment in refrigeration), René Descartes, the great antagonist of Baconian ideas, was catching the popular fancy in the interests of science in France and Holland.

Descartes was Bacon's junior by thirty-five years. He was thirty when Bacon died, and he did not begin to publish his scientific and philosophical conclusions till he was forty-one. Like Bacon, Descartes was of noble lineage and early showed a high degree of mentality. At the age of eight he was sent to a Jesuit school in France, where he quickly mastered all that was offered; that is, the "learned languages and polite literature." This failed to satisfy him, however, and at sixteen he decided that he did not wish to study further. Two influences handicapped Descartes at this time: he had a delicate constitution, and an over-indulgent father granted his every whim. His whole up-

bringing was that of an idle gentleman of wealth and station, and he found it hard to take life seriously. After floundering around from the age of sixteen till he was twenty-one, he became satiated with the idle pleasures of Paris, to which he had aimlessly betaken himself, and joined the army.

Soon afterward an incident occurred which stirred his latent genius. A placard had been posted in the Dutch town of Breda in which he was garrisoned, challenging the world to solve a problem in geometry. A year or two before, in Paris, two friends had endeavored to awaken his interest in mathematics without apparent success; but now the problem on the poster aroused him, and to his surprise he solved it with ease. Before long he was surrounded by a circle of friends in Breda who discussed mathematical and philosophical subjects with him. He now undertook a serious study of mathematics, for his military duties at the time were merely nominal.

Two years later, while pondering over a possible relationship between the hitherto separate subjects of algebra and geometry, an idea flashed across his mind which he subsequently developed into a system linking the two subjects together and marking a distinct forward step in mathematical reasoning. This has come to be known as the Cartesian system of analytics or coördinate geometry. It enables us to represent lines, and circles and other curves, by means of algebraic equations, and vice versa. It is the system which forms the basis of the plots and graphs, of weather or population or other changes, that have become familiar to everyone. We take what are called axes, usually drawn at right angles to each other, and lay off years (let us say) along one axis and population along the other. A graph is then plotted to show population changes. In a similar manner any two variables can be linked together by a graphic

curve. The invention of analytical geometry represents an outstanding mathematical achievement, and it paved the way for still more important advances later on.

The night this new mathematical idea flashed across his mind, Descartes tells us, he determined to give up his former life and dedicate himself to the development of mathematical reasoning. Three years later he resigned his commission in the army. After devoting himself for another five years to study and travel, he returned to Paris in 1626 to begin his self-imposed task. Eleven years afterward appeared his celebrated "Discours" on coördinate geometry and other subjects.

In the meantime, he had been working, also, on a philosophical treatise which was to present a new system of the world, but Galileo's fate at the hands of the Roman Inquisition caused publication to be withheld until 1644, when it appeared under the title of "Principia Philosophiæ." This book, containing many matters of extreme importance for science and philosophy, was immediately put under the ban of the church, but it nevertheless received wide publicity and created a tremendous public interest. Especially was this true of one of the hypotheses set forth therein; namely, the theory of vortices, which associated itself with the Copernican system of astronomy, and, illustrating it in a way readily understood by the lay mind, made an effective popular appeal. So enthusiastically was it received everywhere, and particularly in his native France, that in 1647 the French government recognized Descartes' services by voting him a pension.

The theory of vortices was defective in many respects and has long since been discarded. It was at variance even with Kepler's law of elliptical orbits, the truth of which had been clearly demonstrated twenty-six years before. In its broad general outline, however, it paved the way for Laplace's

well known nebular hypothesis to explain the origin of the solar system. The important purpose served at the time by its publication was to focus public attention on new theories as against ancient ones, and it thus hastened the full collapse of the authority of the past.

We may now pause to sum up the essential differences between Descartes's approach to science and that which was advocated but not practised by Bacon. Descartes's theories of analytic geometry and of vortices were due more to that flash of insight which genius exhibits than to anything else. Bacon's inductive method, therefore, tells only half the story of constructive scientific procedure. Imaginative insight is quite as necessary to scientific advance as are observation and experiment. Yet when it comes to determining which of Descartes's two theories is true and which false, Bacon's method provides the only test. The theory of vortices did not accord with the facts and was therefore discarded. The theory of coördinate geometry has been found useful to an understanding of physical phenomena, and for that reason it has been retained.

The complete scientific method, to repeat, includes not only unbiased observation and repeated experiment but also the setting up of carefully drawn hypotheses or theories to account for the facts observed. Such hypotheses are regarded as provisional and are not accepted as proved until tested time and again by additional observations and experiment. Yet proved theories form the basis of scientific generalizations, and without these there could be no progress in science. The great virtue of the inductive test is to separate the true from the false in our theorizing, and the virtue of scientific theories is to explain the observed facts. Both hold a place of importance in the completed scientific method. The argument as to which is the more essential is

just as futile as the argument about the relative importance of a good stomach and good food.

Primitive man mixed up his dream fancies with his waking experiences, and no adequate way was found to separate the true from the false in man's thinking till the Greeks discovered the inductive test. The Middle Ages brought back primitive conditions by submerging observation and experiment. The mixing up of true and false took on a new impetus. The mistakes of the past continued to be perpetuated. Nothing could have been of greater importance than the popularization of the inductive approach. Therein lay the value of Francis Bacon's critical writings. But the pendulum would undoubtedly have swung to the opposite extreme, discouraging all forms of theorizing, had it not been for the contribution of Descartes. We have here again the old contrast the Greeks encountered: intuition over against observation, the imagination versus experiment, theories opposed to facts, deduction and induction. Descartes demonstrated the one; Francis Bacon emphasized the other. Neither appreciated the dual and complementary character of scientific method. With the breakdown of the authority vested in the written word, and with the popularization of science and its methods, the conflict between these two points of view began anew and lasted for a considerable period. Even in our own day each phase of scientific procedure has its exclusive advocates, although it is now quite generally recognized that the one supplements the other and that each alone is incomplete.

§ 2

So much for the dual character of scientific method and for the contributions of Bacon and Descartes in bringing the significance of science to the people. There is still another

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phase of the work of these two men, as bearing upon the scientific renaissance, which deserves emphasis. This pertains to the influence their writings had upon the least established of the fields of scientific inquiry, upon that branch which attempts to study so-called mental as distinguished from physical phenomena; that is, the field of psychology.

In bringing to the fore again the old controversy waged between Plato and Aristotle as to the relative importance of intuition and observation, Descartes and Bacon opened wide the door to nearly related metaphysical speculations previously kept closed through the power of ecclesiasticism. Man in his new-found mental freedom attempted once more to solve the main riddles of the universe—the existence of God and the soul, the freedom of the will, the relative importance of the physical and the mental worlds—believing that many problems related to the inner life of the mind, which still remain outside the pale of scientific inquiry, can be studied by the exact methods of science. It was not appreciated then that these insistent metaphysical questions—though of ultimate concern to every rational being—are as yet beyond the scope of scientific investigation. With the fetters of medieval despotism removed, Bacon and Descartes and their followers examined without discrimination the whole gamut of metaphysical problems, even as the ancient Greeks had examined them —fearlessly and honestly. And the same differences in personality and interests which led Bacon and Descartes to stand at opposite poles in their treatment of scientific method caused them to found opposing schools of metaphysics and mental philosophy.

As in astronomy, the revolt from medieval authority in metaphysics started in Italy, where it led to the martyrdom of Bruno, who not only supported the Copernican theory but broke away from current theological dogmas as well.

He was followed by the Italian Campanella, who laid emphasis upon certain basic psychological facts; but the vigorous reprisals of the Roman Inquisition soon stilled Italian metaphysical and psychological utterance. Meanwhile, in England, the seventeenth century had opened with the virulent attacks of Francis Bacon, not only on all forms of speculation—scientific, ecclesiastical, and metaphysical alike—but on many other current modes of thinking. Bacon demonstrated, among other things, that the human mind has a tendency to accept many statements as proved though no proof whatsoever has been submitted. He pointed out that people have numerous prejudices which they have never analyzed—prejudices handed down from one generation to the next and unquestioningly adhered to; prejudices accepted because of personal idiosyncrasy; prejudices that we get from public addresses or from our friends; and prejudices arising out of dogmatic statements which we accept by virtue of the fact that they have been dogmatically made and for no other reason. Our prepossessions haunt the minds of all of us, Bacon explained, and hamper us in our attempts to think rationally.

Modern psychology has but served to verify this analysis. It has pointed out, in addition, that we engage in much daydreaming, make many snap judgments, easily find excuses for holding fast to our beliefs, and attempt critical thinking very seldom. The formula that will purge us from prejudice and enable us to proceed scientifically most of the time has not yet been found.

We come now to the second half of the seventeenth century, the period following the brilliant work of Galileo, Kepler, Gilbert, Harvey, and Bacon, and at the threshold of which Descartes made his effective appeal. The sectarian conflicts mentioned at the beginning of the last chapter had temporarily subsided, but soon we see France reverse her

rôle of protector of Protestantism and of the independence of states, and plunge the Continent into another turmoil of religious and political intrigue. At the same time, we observe Great Britain, after a brief interlude of political backsliding, abolish the absolute power of kings in her Bill of Rights (in 1688) and become politically and otherwise the most tolerant and progressive among the nations. France was still politically supreme, but England was already threatening that supremacy.

A number of able thinkers in Great Britain followed Bacon's critical analysis of the human mind. Among the outstanding exponents of the English school of thought which now developed were Hobbes, Locke, and Berkeley in the seventeenth century and Hume in the eighteenth. It would be going out of our way to enter into the various speculations of this school; for speculate these men did, despite their belief that they were following the inductive method pure and simple, as one significant fact will serve to demonstrate. The same reasoning which led Thomas Hobbes, a young contemporary of Bacon, to a materialistic conclusion in his analysis of the inner and outer worlds, led Bishop Berkeley, half a century later, to a spiritualistic one. In the interim, John Locke had taken an intermediate position, and in the next century David Hume once more attempted to find a middle ground on this vexing question of the relative importance of mind and matter.

Contemporaneously with Hobbes, René Descartes in France had been throwing his full genius into the scale of speculative theorizing, basing his contentions on mathematical grounds and insisting that by introspection the great truths of metaphysics and psychology can be deduced. His invention of analytical geometry had given him a supreme confidence in intuition. His well known dictum, "I think, therefore I am"—*cogito, ergo sum*—has echoed and re-

echoed from his day to our own. He postulated what he felt were three fundamental hypotheses for metaphysics: first, that the ego exists; second, that God exists; and, third, that the corporeal world exists. Out of these hypotheses he evolved a dualism of mind and matter, and in doing so rendered an important service to psychology by giving dramatic emphasis to the reality of mind. Yet at the same time he rendered her a disservice also, by maintaining that the scientific methods of investigating material phenomena must be essentially different from those used to investigate mental facts. He thus became the founder of the so-called introspective school in psychology.

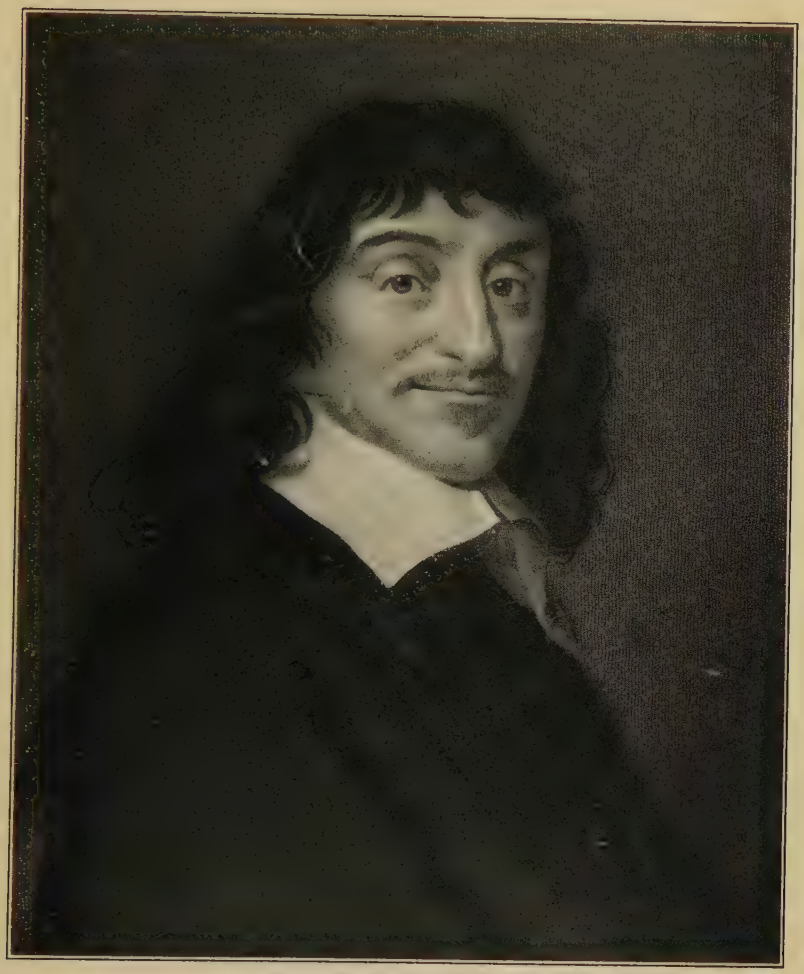
Following Descartes, Baruch Spinoza in Holland indicated many ways in which the dual elements of mind and matter are intimately correlated and yet distinct. And a decade or two after this, about 1684, Gottfried Leibnitz, the great German scientist and metaphysician, reasoned that there is nothing contradictory in assuming that one and the same "essence" can be both mind and matter in different manifestations. Leibnitz became the precursor of the spiritualistic school of metaphysicians, as opposed to the materialism of Hobbes, by hypothesizing that matter in its essence does not consist of deadness and inertia but of energy and force, an assumption quite generally borne out by modern advances in physics but having no known facts to substantiate it in the seventeenth century. In the eighteenth century, Immanuel Kant developed the Descartes-Leibnitz reasoning further.

The metaphysical speculations of Leibnitz were eclipsed in 1690 by the publication in England of John Locke's famous "Essay Concerning Human Understanding," in which he took sharp issue with his German contemporary. Building upon what Bacon and Hobbes had started, Locke insisted that all speculations about the soul, material "es-

sences," and the like were so much folderol, that all knowledge comes to us from the outside world by observation and sensation, and that there is no innate knowledge whatsoever. It was the same battle over again between speculation and observation, with this difference: concurrent advances in physics and mathematics, especially those having to do with sound and light, had given a new meaning to the superficial psychological facts then available regarding sensation, and Locke and Leibnitz and their adherents made use of these new discoveries.

The significant point for us here is that, despite this help from physics, the essential character of the metaphysical controversy beginning with Bacon and Descartes, and continuing for two centuries, remained unchanged. Bearing in mind what was said earlier in this chapter regarding the mutual and complementary character of speculation and observation, of deduction and induction, it is apparent that neither the Descartes-Leibnitz-Kant school nor the Bacon-Locke-Hume school had the whole truth on its side. The contributions of the one lay in pointing out the need for common-sense hypotheses in psychology as in other sciences and in emphasizing the obvious dualism of mind and matter as a starting-point for psychological investigation. Its shortcomings lay in its insistence upon introspection as the only psychological method, which meant that this science must secure its facts in ways different from those of other sciences, and in its failure to appreciate the value of induction for purposes of separating useless and futile speculations from those that can be utilized as tentative hypotheses for further psychological fact gathering.

The chief contribution of the English school lay in insisting upon observational and experimental methods, which insistence led finally to the abandonment of untrammeled speculation in psychology. Its shortcomings lay in its in-



·DESCARTES

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ability to appreciate the value of carefully drawn hypotheses for scientific purposes, and in its use of metaphysical theorizing despite its protests to the contrary. Its attempts to explain mind away in terms of matter (Hobbes) and matter away in terms of mind (Berkeley), and its efforts to determine whether we can really know anything or not, were just as futile metaphysical excursions as the theorizing of the school it opposed.

The real difficulty of seventeenth and eighteenth century psychology was appreciated by neither school; namely, there was too much speculation with too few facts to go on, which facts, in addition, were exceedingly superficial. Advance for psychology lay in reducing the speculative theories to an irreducible minimum—a minimum on which all workers could agree—and in collecting more and better psychological facts. Yet it must not be overlooked that it was just such discussions as Locke and Leibnitz engaged in, wholly speculative and largely futile so far as psychology proper was concerned, which led to a clearing of the atmosphere, a separation of metaphysical from psychological interests, and a definition of the scope of the new science.

Out of the smoke of argument and counter-argument lasting for another century after Locke, it ultimately became clear that psychology must rest her claims to be called a science on more modest grounds than metaphysical ones. Once more the main riddles of the universe had to be put aside. Not that this renders these vital questions one whit less important or insistent. It simply emphasizes that, as yet constituted, scientific knowledge is unable to encompass them. First the demonstration of the existence of God or the soul had to be excluded from psychological consideration. Then the scientific proof of an "essence," linking mind and body together and making them one, was likewise set aside. And, finally, it came to be appreciated that to try to

argue matter away in terms of mind, or mind away in terms of matter, was equally futile for psychology. Not until psychology settled down to accepting the dualism of mind and body as a working hypothesis, and turned over to metaphysics the other questions mentioned, could it proceed to build upon a secure and acceptable basis. And yet even to-day there are psychologists who persist in confusing psychological with metaphysical issues, not content apparently with the less pretentious hypotheses underlying modern psychology.

With respect to the meagerness and superficiality of seventeenth and eighteenth century psychological facts, two points will bear emphasis. One is that the Cartesian insistence on introspection as the distinctive method for psychological investigation served for a considerable period to prevent psychologists from looking in the right direction for further facts. The other concerns itself with the intimate relation between psychological and biological data. The biological facts upon which modern psychology depends—that is, those having to do with the functioning of the brain, the spinal cord, the sense organs, and the rest of the nervous system—were not available during this period. In the interim, clearing the atmosphere of metaphysical presuppositions was a most necessary first step to later constructive advance.

§ 3

Progress in natural history, as geology and biology were still called, was also tremendously stimulated in the second half of the seventeenth century. Cordus, Vesalius, and Harvey had broken away from the authority of the ancients in biology, and physics had advanced to the point where the microscope could be made use of in nature study. Many of the mathematical physicists of Galileo's day and immedi-

ately following worked on the problems of optics, and by the middle of the century lens makers arose in England and on the Continent who supplied usable microscopes and telescopes. Just as the telescope stimulated astronomical progress, so the microscope stimulated biological and geological progress.

In 1665 a remarkable book, entitled the "Micrographia," was published by the versatile naturalist and physicist Robert Hooke, in the preface of which the value of the microscope to the naturalist is expressed thus:

> The next care to be taken, in respect to the senses, is a supplying of their infirmities with instruments, and, as it were, the adding of artificial organs to the natural; this for one of the senses has been of late years accomplished with prodigious benefit to all sorts of useful knowledge, by the invention of optical glasses. . . . It seems not improbable, but that by these helps the subtlety of the composition of bodies, the structure of their parts, the various textures of their matter, the instruments and manner of their inward motions, and all the other possible appearances of things, may come to be more fully discovered.

Hooke's volume is replete with illustrations of microscopic examinations of animals and plants and makes mention for the first time of those "little boxes or cells" which were later to be recognized as among the fundamentals of scientific biology. Two contemporaries of Hooke, Leeuwenhoek and Swammerdam, opened up the "world of the infinitely small" with their microscopes as Galileo had opened up the heavens with his telescope. The work of these two Hollanders was of outstanding importance. The microscopic school, which they represent, created an epoch for biological research.

The greatest biological thinker of this period, however, was Marcello Malpighi of Bologna (1628-1694), an out-

standing genius. Malpighi developed many branches of biological study previously non-existent. At seventeen he was already amusing himself with the microscope. At twenty-one he entered the University of Bologna to study medicine. Later he was professor of medicine at the Universities of Pisa, Messina, and Bologna. He served his native university for more than twenty-five years, until in failing health he withdrew to Rome to become private physician to Pope Innocent XII. Upon Malpighi's death three years later, his writings were carefully preserved and published.

Malpighi's discoveries in human physiology are on a par with those of his illustrious predecessor, Harvey, and in a way completed them. Six years before Harvey's death, Malpighi discovered, and Leeuwenhoek later amplified the discovery, that the blood circulates not only by way of the arteries and veins but likewise by means of fine, hair-like tubes or capillaries connecting the arteries and veins at various points and now known to extend to the minutest parts of the body. Without the microscope these hair-like tubes could not have been discovered, nor could the blood corpuscles, which Malpighi discerned several years afterward. Malpighi was among the first to use the microscope with scientific effect in the study of animal and vegetable structures. He combined this study with his practice of vivisection with striking results. In this way he analyzed the structure of the lungs, the kidneys, the spleen, the skin, and the brain. Many paths opened out from Malpighi's work, some of them leading to the special fields known to-day as classification, histology, plant physiology, embryology, and genetics. He did pioneer work in geology also.

Although Malpighi, Leeuwenhoek, Swammerdam, and others during this period were making notable biological advances by means of the microscope, the basic facts of anatomy, physiology, and embryology still remained to be

worked out. Until they were, so many false theories held the field that a proper scientific perspective in biological research was impossible. Malpighi himself, though he paved the way for important later discoveries, held false conceptions regarding the origin of life and the structure of animal tissues. Concerning the origin of life, many speculations, fantastic to us with our wider knowledge, were being put forth. Highly developed vertebrates, such as eels, were conceived as spontaneously generated out of the void or out of mud, and fossils were regarded as the remains of half-formed beings, uncompleted, much as though the Creator got tired while he was fashioning them and left them only partly finished. Redi and Steno, contemporaries of Malpighi, made noteworthy attempts to dispel these false notions; but Steno's pamphlet on geological formations, published in 1669, the most important geological document of that century, received no attention till many years later, and Redi's pioneer experiments to show that maggots are not spontaneously generated out of decaying meat, but are produced from flies' eggs deposited on the meat, proved inconclusive. Only within recent years has the last of these misconceptions been thrown into the discard. In Malpighi's day, too few microscopic facts had been brought to light, and virtually nothing was known about the important foundation subjects of organic and inorganic chemistry, to dispel the false theories thrown about biology and geology.

In this respect, the observation must be repeated which was made regarding the psychological development of the renaissance period. Just as the complete clearing of the atmosphere in psychology had to await the firm establishment of biology, certain fundamentals in physics and chemistry had to be established before the false theories of the fields of nature study could be swept away. The revolutionizing effect upon biology of the application of the micro-

scope (a product of physics) has already been indicated. Further progress in physical science had to come before biology and geology could lay the substructures of their respective sciences. The fact gathering and exploration of the world of the microscope were being carried on as necessary preliminaries.

§ 4

The effect of the scientific renaissance upon chemistry and physics was even more important than its effect upon the fields just reviewed. Chemistry had not yet become a distinct department of scientific inquiry, but the foundation-stones of physics were ready to be laid when Galileo had completed his epoch-making researches in mechanics. Descartes's invention of analytic geometry was likewise important for advances here. Soon after the middle of the seventeenth century, in fact, physics was placed upon a scientific basis. Somewhat earlier, also, scientists interested in border-line problems involving both chemistry and physics were doing constructive work in clearing away misconceptions surrounding these fields.

At the beginning of the seventeenth century, to retrace our steps for a moment, many false notions of long standing were clinging to those intangible phases of physical and chemical phenomena having to do with the atmosphere, and with heat, light, sound, electricity, and magnetism. Although Galileo and Gilbert had exposed some of the erroneous beliefs bound up in astrology and alchemy, many others were rife, and some continued for a century or more. Prominent at this time among the pioneers who struck out boldly against age-old superstition was a young English contemporary of Galileo, Robert Boyle (1627-1691).

Born in Ireland a year after the death of Francis Bacon and fifteen years before Galileo died, Robert Boyle, the

seventh son of the Earl of Cork, was favored both by heritage and environment. Robert was precocious as a child and highly susceptible to suggestion, as is evidenced by his picking up the habit of stuttering from one of his playmates, a habit which later proved to be unbreakable. When eight years old he was sent to England to be educated at Eton, where he remained four years. By the age of twelve, he had mastered a considerable portion of Latin, French, and mathematics, and was engaged in writing verse and studying the Scriptures. No signs of scientific predilection had manifested themselves at this time. His emotional susceptibility was in fact inclining him toward the ministry, and he remained devoutly religious throughout his life. In 1638, he began a six-year trip with a brother, visiting and studying in Holland, France, Switzerland, and Italy. He arrived in Italy at the time of the passing of Galileo and made a study of the life and works of the celebrated Italian. This impressed him profoundly and probably did more than anything else to start him on a scientific career.

Boyle was seventeen when he returned home in 1644, upon the death of his father (his mother having died when he was a child of three), and found himself heir to a considerable estate. The next ten years was an unsettled period for him, although by no means an unprofitable one. Most of his time was divided between his Irish estates in Ulster and the home of a sister who lived in London. England was in a political turmoil; but a small group of investigators, uninterested in politics, had banded themselves together in London to discuss philosophic and scientific problems, and Boyle spent many pleasant and profitable hours attending their gatherings. When in 1654 he moved to Oxford to equip a laboratory and settle down to serious experimental work, he and others continued these informal gatherings there. Soon their importance became generally recognized,

and in 1660, through the aid of King Charles, the Royal Society for the Advancement of Learning was officially created. To-day the highest distinction a scientist can receive in England is to be elected a fellow of this society and to be allowed to place "F.R.S." after his name.

Boyle was a member of the council of the Royal Society from its inception, and most of the meetings which preceded its formation and for some time afterward were held in his laboratory at Oxford. These brought together the most eminent English scientists of the day, and many important problems came up for discussion. As a result Boyle became particularly interested in the current practices and claims of the alchemists, on the one hand, and, on the other, in the experiments with the atmosphere and its relation to pressure and suction that were being carried on in Italy, France, and Germany.

In 1661 he published an important work entitled "The Sceptical Chymist," in which he severely criticized charlatanry and urged that chemistry be studied for its own sake. Up to that time chemical phenomena had been pursued chiefly as an aid to alchemy and medicine. In his book Boyle questions the practices of the alchemists. He complains that they play with words, that their writings are intolerably ambiguous, and that they deliberately obscure their meanings. He writes:

> If judicious men skilled in chymical affairs shall agree to write clearly and plainly of them, and thereby keep men from being stunned, as it were, or imposed upon by dark and empty words, 'tis to be hoped that these men [the alchemists] finding that they can no longer write impertinently and absurdly, without being laughed at for doing so, will be reduced either to write nothing, or books that may teach us something, and not rob men, as formerly, of invaluable time; and so ceasing to trouble the world with riddles or imper-

tinencies, we shall either by their books receive an advantage, or by their silence escape an inconvenience.

The alchemists had had things largely their own way. They—as well as the astrologers—had taken the so-called elements of the ancient Greeks—earth, air, fire, and water—and had built upon them a mysterious "system" through which they asserted base metals could be transmuted into gold and an elixir of youth could be compounded. In these latter days we have actually succeeded in transmuting one element into another and by gland transplantation and other means have made the aged young again, so that we cannot say that the dreams of the alchemists were entirely fantastic. It was not their dreams which were misleading but their practices. Leaving out of account the charlatans who fattened on tribute from their dupes, those alchemists who were in earnest were not going at things in a scientific way. They accepted the written words of previous alchemists and by various processes of hocus-pocus hoped to hit upon the objects of their search. Boyle's book discredited this whole procedure and urged a new approach.

He insisted, among other things, that the alchemists' use of the term "element" was misleading, and that it should not be applied to compounds of more elementary substances, but only to "certain primitive and simple, or perfectly unmingled bodies; which, not being made of any other bodies or of one another," are the ingredients out of which compounds are made and "into which they are ultimately resolved." This distinction between chemical elements and their compounds, first proposed by Boyle in 1661, is still adhered to at the present time. No generalization has proved more serviceable for chemical advance.

To-day we know that none of the four things labeled

"elements" by the ancient Greeks is such in any real sense. Water is a compound of the two elements hydrogen and oxygen; the earth and the air are composed of many elements; while fire is neither an element nor a compound but a misleading phenomenon which accompanies combustion and which was not understood until comparatively recent years. In Boyle's day fire was thought of as material in character (which it is not), whereas the material nature of the air had not yet been fully recognized.

Before Galileo, virtually nothing was known about the atmosphere, the prevailing ignorance being summed up in the dictum laid down by Aristotle that Nature "abhors a vacuum," and, horrified at seeing one, causes explosions and other noises in her haste to fill empty spaces with air. This crude notion served to explain in part many otherwise inexplicable happenings. If the air, for example, is sucked out of a vessel having only one small opening, no way being provided for other air to get in and the walls of the vessel being fairly thin, why should the walls collapse with a sudden bang unless Nature were disturbed about the situation? It was not then known that air is material and has weight, and therefore exerts considerable pressure against anything with which it is in contact. The air in a vessel presses against the inside walls, counteracting the push from without. Remove the internal pressure of the air by withdrawing it, and the walls may be unable to sustain the outside push. With the actual causes unknown, the effect of a vessel's collapse under circumstances as just described must have been startling.

Galileo had satisfied himself that the air has weight by weighing a vessel filled with it and then forcing in additional air and weighing again. Two of his pupils (Torricelli and Viviani) went further and demonstrated that, under suitable conditions, the pressure of the atmosphere will actually

hold up or sustain a column of mercury. To understand the Torricelli experiment, one need but picture an inverted glass test-tube suspended over a dish of mercury with the open end of the tube just immersed in the mercury and the air in the tube removed—by some means that we need not go into. The push of the air on the mercury in the dish will force the mercury up into the inverted test-tube for a certain distance, since there is no air pressure in the tube to counteract and prevent this.

Pascal, a young French genius, took the next step. He argued that if Torricelli's conclusions regarding air pressure are correct, the height of his mercury column should grow less as one ascends into high altitudes, where the air is rarer and therefore must exert less force. Arranging that a Torricelli tube be taken to the top of a mountain, Pascal found that the mercury column dropped three inches in the ascent, thus giving further support to Torricelli's experiment and initiating the use of barometers for measuring atmospheric pressure. Torricelli's tube constituted the first barometer.

Meanwhile in Germany even more surprising results of experiments on air pressure were forthcoming. A German scientist by the name of Guericke had tried to draw water from a tightly sealed cask, but he could not prevent air from getting in. Then he substituted a copper sphere for the cask, with the result that after he got most of the water out, the sphere collapsed, "with a loud clap and to the terror of all." He finally did succeed with heavier material in securing a partial vacuum and carried out experiments under varying air pressures. Some of his results were: "A clock in a vacuum cannot be heard to strike; a flame dies out in it; a bird opens its bill wide, struggles for air, and dies; fishes perish; grapes can be preserved six months in vacuo." Guericke then showed how great the push of the air is by

performing his famous experiment of the Magdeburg hemispheres, which were hollow metal shells about a foot in diameter. After putting the hemispheres together and exhausting the air in the hollow interior, he demonstrated before Emperor Ferdinand and the Diet of Germany in 1654 that it required the combined strength of sixteen horses, eight pulling on one hemisphere and eight on the other, to separate them. The hemispheres were held together only by the pressure of the air on the outside.

This spectacular experiment occurred in the year in which Robert Boyle at the age of twenty-seven settled in Oxford, established a laboratory, and employed Robert Hooke as his assistant. Hooke was himself to become famous as a scientist, and we have already had occasion to mention his name in connection with the microscopic school of biologists and the publication of his "Micrographia." This book appeared eleven years after he began work as Boyle's assistant.

Robert Boyle had followed with considerable interest the experiments on atmospheric behavior conducted by his contemporaries in Germany, Italy, and France; and with the assistance of Hooke he determined to go further. To begin with, he perfected an air-pump on the plan of Guericke's but much more efficient, which enabled him to experiment with ease at pressures both less and greater than that of free atmosphere. He then verified a number of Guericke's results, showing that sound will not travel in a vacuum, that combustion cannot proceed without air, and that without it animals, birds, and fish cease to live. He also demonstrated that, although sound does not travel in a vacuum, both electricity and magnetism do, a distinction which proved later to be of the utmost importance for the science of physics. He performed many other interesting experiments into which we cannot go here.

The most important of Boyle's discoveries was the formulation of the law which bears his name, the law indicating the relation of gas pressure to volume. By means of a series of carefully planned experiments he found that at a constant temperature the volume of a gas such as air is decreased in proportion as the pressure applied to it is increased, and vice versa. For example, if the pressure applied to a gas is doubled, its volume is decreased fifty per cent; if it is cut in half, the volume is doubled, and so on. If V is taken to mean volume and P pressure, the following equation expresses this relationship: $P = \frac{K}{V}$, where K is a constant which remains fixed for a given gas but has different values for different gases. Expressed otherwise, the equation reads: $PV = K$. It is to be remembered that this relationship holds only when the gas is kept at a constant *temperature*. Later it was discovered by another physicist that if the *pressure* is kept uniform, a constant ratio is also found to exist between temperature and volume. As temperature increases, the volume expands in direct ratio, and vice versa. Both these laws are now known to hold only for ordinary temperatures and pressures.

Boyle's law has proved to be of supreme scientific importance, both for chemistry and physics. It has been found by experiment to apply not only to air, with which Boyle experimented, but to nearly all other gases. In Boyle's day many things pertaining to gases were undiscovered. Air was the only one known, and this, as is now well understood, is itself a mixture of a number of them. There are, of course, also other gases not found in ordinary air.

Boyle's painstaking experiments brought universal recognition. They gave added meaning to the inductive method emphasized by Francis Bacon and helped prevent the swing toward Cartesianism and speculation from going too far.

Boyle, a humble and devoutly religious man, declined all the honors that a grateful contemporary world would heap upon him. Not that he failed to arouse opposition—many hailed the results of his experiments as destructive of religion and as undermining the authority of the universities. Science, however, had become more widely known. Its benefits were being recognized. And the violent and destructive criticism of even a generation before had been greatly diminished. Boyle had a delicate constitution and during his later years was frequently ill, but his resources were plentiful and enabled him to live a protected life. He found great joy in his work. As he said, "In my laboratory, I find that water of Lethe which causes me to forget everything but the joy of making experiments."

With Boyle's researches on atmospheric behavior following Galileo's in mechanics, physical science received a tremendous forward impulse. Yet all this was but a harbinger of the truly revolutionary effects produced by the work of one of Boyle's later contemporaries, the noted English statesman and scientist, Sir Isaac Newton.

CHAPTER VI

PHYSICS ESTABLISHED AS A SCIENCE

§ 1

In reviewing the accomplishments of Newton, it should not be forgotten that we are still concerned with that remarkable period of development (designated in these pages as the scientific renaissance) which followed the pioneer work of Galileo, Kepler, Gilbert, and Harvey, and Bacon's and Descartes's appeal to the popular imagination in the interests of science. We come now, in fact, to the crowning achievement of that period. Nor should the effects of the renaissance in the fields we have just reviewed and the achievements of certain of Newton's contemporaries, such as Robert Boyle, be overlooked in appraising what Newton wrought. Newton was not an isolated phenomenon. He came at a time ripe to receive him. What his immediate predecessors and his close contemporaries achieved in mathematics, astronomy, and physics, paved the way for his own brilliant accomplishments.

It should likewise be remembered that Great Britain in the second half of the seventeenth century was in a better position to foster scientific research than any other part of Europe. In France and Holland independent thought flourished for a time; but soon after the middle of the century the two nations clashed in mortal combat, and scientific interests were submerged. In the conflict Holland fell from power, France was weakened and humiliated, and England moved toward her political ascendancy. Germany had in the interim become, like Spain, Italy, and Austria, a country

in which science could not advance except under severe handicap. Great Britain alone remained tolerant and mighty.

Besides the Englishman Boyle and his assistant Hooke, there were other celebrated scientists who in one way or another are associated with Newton and his work, such as Edmund Halley, the discoverer of the comet which bears his name. We cannot even cursorily review the life of each one of this splendid galaxy without deviating too far from the main current of our theme. Yet there are two men, at least, who should be considered somewhat carefully because of the immediate bearing of their work on that of Newton. These are Christian Huygens, the eminent propounder of the wave theory of light, and Gottfried Leibnitz, whom we have already had occasion to mention in connection with his contributions to the metaphysical and psychological controversies of the time. Since most of the latter part of this chapter will concern itself with Newton primarily, Leibnitz and Huygens will be briefly dealt with here.

Leibnitz (1646-1716) was a most remarkable German philosopher and scientist, in that he made important contributions to three widely separated scientific fields—mathematics, geology, and psychology. In geology he formed the link between Descartes and Laplace in the development of a notable theory concerning the evolution of the universe. Of his work in psychology we have already spoken, and of his achievements in mathematics more will be said presently.

Leibnitz mastered Greek and Latin at an early age, later becoming a close student of Plato and Aristotle, whose views he endeavored to reconcile. At twenty, he had also mastered sufficient law to qualify for a law degree at the University of Leipsic in his native city, but because of his youth the degree was refused him there, though he secured it elsewhere the same year. Four years later, in 1670, he was appointed to an important judicial office. In 1672 he

visited Paris and London and became acquainted with Newton, Boyle, Huygens and other eminent scientists. He was then only twenty-six, yet his fame as a philosopher and scientist had already spread, and, during his stay in London, he was chosen a fellow of the Royal Society. Later he organized scientific societies in various German cities and in St. Petersburg at the suggestion of Peter the Great of Russia, who bestowed a pension and title upon him. Leibnitz was honored, likewise, in other countries and especially in his native Germany. He was eminent in "history, divinity, philosophy, political studies, mathematics, mining, experimental science, and belles-lettres"—a truly remarkable genius, a man whose life and works are well worth detailed study.

Huygens (1629-1695) excelled as a mathematician, astronomer, and physicst. He was born in Holland into a family of prominence, and inherited the title of Lord. His father was a celebrated Dutch writer, and his grandfather was secretary of the State Council. Huygens studied at the universities of Leyden and Breda, beginning (like Leibnitz) with law, but later turning to mathematics, which he soon mastered, publishing a book on the subject at the age of twenty-two.

Branching out from mathematics, Huygens took up astronomy and physics, doing notable work in both these fields, especially with respect to the planet Saturn and its rings and with respect to theories of gravitation and light. His genius for mechanical invention attracted wide notice. He was also elected a fellow of the Royal Society in England early in life and was associated with the Academy of Sciences in Paris for a number of years.

Huygens was twenty-eight when in 1657 he went to Paris, then still one of the centers of liberal thought, to prosecute experiments on the pendulum initiated by Galileo. Here he

constructed the first pendulum clock, applied Galileo's theory to an accurate determination of the force of the earth's gravity, and worked out the principles of so-called centrifugal force, which is the force needed to keep a body moving in a circular or quasi-circular path. Newton was heavily indebted to Huygens for these splendid contributions when he came to determine the law of universal gravitation.

At the age of fifty-two, Huygens returned to Holland from France and began the construction of enormous telescopes, one of which had a focal length of 210 feet. He spent some years on this work and on a study of optics and light. In 1690 appeared his "Treatise on Light," one of his major achievements, in which his undulatory theory is set forth in detail. This book also contains an account of the polarization of light, a peculiar effect produced by certain substances such as tourmalin when light passes through them. Light striking such substances from all directions succeeds in getting through in only one "plane." It is an interesting fact that polarization, which Huygens discovered, is the one thing which his undulatory theory as he conceived it could not explain and which led Newton to reject it. Huygens thought of light traveling in longitudinal waves, as sound does. Experiments a century or more later proved that light travels in transverse waves, with which correction the undulatory theory explains polarization and is accepted to-day.

Both Huygens and Leibnitz remained bachelors, as did Newton also. Thus the unusual endowments nature gave to these three geniuses of science presumably died with them.

§ 2

Turning now to the early life of Sir Isaac Newton (1642-1727), we note that he was born the year his great pre-

decessor Galileo died. Newton was a sickly child and gave every indication of a short life. He belied all expectations on this score, however, by living to the advanced age of eighty-five.

We have said that Newton was not an isolated phenomenon. At the same time he towered head and shoulders above his contemporaries. His accomplishments in mathematics, astronomy, and physics have not been surpassed by any man. Than Newton no scientist has been greater. England may well be proud of one of her noblest sons.

Newton's father, who died before Isaac's birth, had been a farmer, and various efforts were made to induce Isaac to devote himself to the cultivation of the soil. But the boy would have nothing of it. His mechanical inclinations had early become apparent. He made windmills, water-clocks, and other devices, and in a spirit of mischief is said to have tied lanterns to the tails of kites, sending them up at night to delude his fellow-townsmen into thinking they were watching comets. Finding that Isaac would not be a farmer, his mother finally allowed him to be prepared for Trinity, one of the colleges of Cambridge University, which he entered at the age of eighteen.

Hitherto Newton had had little opportunity for displaying his prodigious intellect; but at college he soon outstripped all his classmates, finding the scheme of lectures too slow, and on the side mastering in rapid succession Euclid's "Elements," Kepler's "Optics," and Descartes's "Geometry." Very soon he had devoured everything mathematical he could lay hands on and was engaging in frequent discussions with the professor of mathematics, Isaac Barrow, who recognized Newton's remarkable ability and encouraged him as much as he could. Barrow was himself a most distinguished mathematician and must be given credit for much that Newton now undertook. With mathe-

matics, he studied astronomy and physics, all of which took a strong grip on his imagination.

Newton was twenty-two when Trinity in 1664 awarded him the A.B. degree. He intended to stay on, but a plague closed the institution, and he went home for eighteen months. When the college reopened, he returned as a fellow. In 1669, after receiving his M.A. degree and upon the gracious resignation of Barrow in his favor, Newton was offered the chair of mathematics at his alma mater. This professorship he accepted and continued to hold for thirty-four years.

It is well to pause here, before completing our sketch of Newton's life, to examine the reasons behind the selection of a young man of twenty-seven as a professor in Cambridge University. These reasons will take us into the most revolutionary of his accomplishments in mathematics, astronomy, and physics; for the years just preceding and following the taking of his A.B. degree were the prolific years of his remarkable career. During this early period, his most fertile work was begun and in some respects brought to completion. Newton had barely passed twenty-one when he began making the experiments and formulating the hypotheses which have come down to us as the greatest scientific generalizations of all time.

The plague years of '65 and '66 were not a calamity for Newton. They provided a great opportunity. For eighteen months he was able to reflect on various scientific problems undisturbed by routine study. He had time to digest the lessons learned at Trinity. He could go out into the open, watch the leaves and the fruit fall from the trees in his orchard, and at night look up at the starry heavens and wonder and dream. As he himself said of this period later on, "In those days I was in the prime of my life for inven-

tion, and minded mathematics and philosophy more than at any time since."

It was during the plague years that Newton experimented with his method of "fluxions," now called the calculus, the application of which has revolutionized the entire science of mathematics. Building upon the new foundations laid by Descartes in his coördinate geometry, Newton introduced a mathematics of things in motion, whereas, before, mathematics had dealt mainly with things at rest.

The Cartesian mathematical device had fascinated Newton, and we may well picture him in his undergraduate enthusiasm plotting curves to represent not only abstract algebraic relations but the practical equations of Kepler and Galileo embodying the laws of planetary motion and of falling bodies. Kepler's third law, $r^3 = kt^2$, and Galileo's falling body law, $d = k_1 t^2$, could be plotted. So could other practical relationships. But the whole procedure was still static. No dynamic element had been introduced.

The revelation which came to Newton in this connection was that the concept of fixity in plotted figures is unnecessary. Whatever credit should be given Leibnitz and other mathematicians of that period, especially to the Frenchman Fermat, who all but created the calculus in the preceding generation, the idea of motion and change was apparently not in their minds. They were more concerned with abstract mathematical technique, with drawing tangents to curves, with finding the lengths of curves, and with calculating areas inclosed by curves. It was Newton who seized upon the revolutionary conception of a mathematics of motion and applied it so successfully to practical problems.

Newton asked himself: Why not regard the circle, for example, as generated by a point moving in the path of the curve? Having raised the question, he proceeded to work

out ways and means for determining mathematically how fast, for a given curve, the point should be regarded as moving at one position as compared with others. The relative rate with which this imaginary point was presumed to move he designated the curve's "fluxion."

All nature is pregnant with change. How fast is a falling body moving? A cannon-ball, light, an electron, a planet? Are they moving with uniform or variable speeds? If variable, is there any way of calculating the speed, or rate of change of speed, at any given time? These are the kinds of questions with which we are confronted in nature; and a mathematics of motion, of rates of change of motion, furnishes a key with which the most important problems of physics can be unlocked. Without entering further into the intricacies of this conception, we can but repeat that important practical problems could now be readily solved by the new mathematical technique.

Newton called it the method of fluxions, but it came to be known as the calculus, following the terminology used in the mathematical writings of Leibnitz, which proved the easier terminology to understand, although Newton's was the more accurate.

The invention of the calculus or method of fluxions marks a mile-stone in mathematics. It marks, also, an unpleasant controversy between its two founders. Newton formulated his method while away from Trinity during the plague in 1665. He did not make it public until 1693, twenty-eight years later, although his manuscript had been circulated among friends as early as 1669, and Leibnitz had seen it about 1676. In 1684 Leibnitz published his theory of the calculus, nine years before Newton published his method of fluxions. Newton's friends accused Leibnitz of taking the idea from Newton, and Leibnitz retaliated by accusing Newton of having plagiarized from him. It was a long and

painful dispute, the net result of which was that Leibnitz's calculus, with much the better notation, came to be used almost exclusively on the Continent, while Newton's more complicated method of fluxions was used in England. Because of the superior symbolism of the former, higher mathematics made tremendous strides outside of the British Isles, while in Newton's own country little mathematical progress was made after his time for a considerable period.

We appreciate now, in retrospect, that both Leibnitz and Newton should be given credit for a joint invention. Regardless of whether the one borrowed from the other or both from Fermat and Barrow, Newton furnished the philosophy of motion and rate of change which lies behind the calculus, and Leibnitz furnished the practical notation which has persisted to the present day. And, curiously enough, Newton is known as a practical scientist and Leibnitz as a theoretical philosopher!

So much for the part Newton played in the discovery and development of a new mathematical tool. We might stop to mention some of his further contributions to mathematics, such as his discovery of the binomial theorem while still an undergraduate at Trinity, but this would again take us too far afield. One other fact, however, deserves special emphasis here. Newton soon lost his fascination for mathematics as a thing in itself and came to regard it more and more as a practical tool for solving the problems of physics and astronomy. There were a number of noted mathematicians in his day, but none appreciated as he did the value of mathematical symbolism as a short-cut method of scientific reasoning, of compacting many observations and ideas into a single mathematical formula more readily understood.

Newton's speculations regarding gravitation, the most profound and revolutionary of any before Einstein, were also begun during the two plague years of 1665-1666.

Galileo had demonstrated that a body falling to earth behaves in a certain way; that is, its velocity is not uniform but increases directly as the time of falling ($v = k_1 t$), and its distance of fall increases as the square of the time ($d = k_1 t^2$). Kepler had shown that planets move in elliptical orbits and that the cube of their mean distances from the sun varies as the square of their periodic times ($r^3 = kt^2$). These facts were turning themselves over in Newton's mind, and he was wondering if there could be any relationship between them—the same old wonder which has been at the basis of so many important discoveries. We all know the story of how the fall of an apple from a tree is supposed to have started him on this train of thought and to have raised the question: Is the force which pulls the apple to earth the same force that keeps the planets in their courses? What a Dionysian thought this! How it must have stirred him to the depths as he propounded it! He determined to find the answer, and his law of universal gravitation is the sequel.

The conceptions of force and gravity were not novel in Newton's day. Speculations on these subjects had come down from the ancient Greeks. The power or force which pulls things to earth was, generally speaking, well known. Galileo had worked out the laws of its behavior with respect to the earth, and in Newton's own day Huygens had determined the quantitative extent of its pull at the earth's surface; but no one apparently had thought of it as reaching out into space and holding the planets in their courses. It was Newton who first conceived of gravitation as a universal force, applying not only to terrestrial affairs but to everything everywhere.

The first problem he faced in attempting to reconcile Galileo's and Kepler's laws was to account for the elliptical

orbits of the planets as against the straight-line fall of the apple. The apple had previously been at rest on the apple-tree. If a planet had previously been at rest, back at the beginning of things, and obeyed the same law as the apple, it must surely have fallen into the sun after beginning to move, just as the apple falls to earth. But possibly the planet had not been at rest? Possibly it had had an initial motion of its own? Possibly rest is not the only natural condition of a body, as Aristotle had supposed? For if the planet had had an initial motion, it might have been able to resist the straight-line pull of the sun's gravity sufficiently to have avoided falling in, even though in the process it was made captive by the sun and doomed forever to circle around it.

The assumption involved in the reasoning of the preceding paragraph is now known as Newton's first law of motion and is, in brief, that every particle of matter in the universe is in a state of rest *or of uniform motion in a straight line* unless acted upon by some outside force. By adding the italicized phrase "or of uniform motion in a straight line" to Aristotle's hypothesis that "rest" is the only natural condition of bodies, Newton was able to explain both the straight-line fall of the apple and the elliptical orbits of the planets. Assuming that at the beginning the planets possessed a uniform motion in a straight line and that, as they were passing the sun, they were bent out of this course by the sun's gravitational pull, Newton now set about demonstrating mathematically that their present elliptical orbits can be looked upon as an equilibrium of their assumed initial motion and the force of gravity of the sun.

So much for Newton's first assumption, as a corollary to which force came to be defined as anything which causes or tends to cause a change in the motion of a body. He had

resolved the straight-line fall of bodies to earth and the elliptical paths of the planets into one underlying formula, but other problems were still ahead.

A second one was to measure the amount of gravitational force being applied in a given instance. So far as the earth is concerned, this had already been worked out by Galileo, who had proved two things: first, that the relation between the earth's gravitational pull and the mass or density of a body it is attracting is a direct one ($F = k_1 m$); and, second, that the velocity produced varies directly with the time of falling ($v = k_1 t$). Combining the ideas involved in these two equations, Newton enunciated his famous "force equals mass times acceleration" formula ($F = ma$) which is now spoken of as his second law of motion. Acceleration is the rate of change of the speed with which a body is moving; that is, velocity divided by time, or $a = \frac{v}{t}$. From Galileo's two equations we get $F = \frac{mv}{t}$, and substituting we get Newton's second law.

The reader need not feel discouraged if the foregoing reasoning appears technical. Coming as an unfamiliar piece of deduction, it needs to be pondered carefully before it is entirely clear; and it must be remembered that it represents one of the most profound generalizations of all time.

We have traced the carefully formulated deductions leading up to what are now generally considered as two inexorable laws of motion. Regarding the testing out of these laws we have still to speak. Before this could be accomplished, however, Newton found it necessary to lay down a third hypothesis. He was trying to work out a formula for a force of gravitation acting between any two bodies anywhere in space. Take, for example, the earth and the moon. Which way shall we consider the assumed gravita-

tional force between them to be acting, from the earth to the moon, from the moon to the earth, or in both directions? Obviously the third alternative is free from difficulty. It is the one Newton chose, stating that "to every action there is an equal and opposite reaction." This is now called his third law of motion.

Having cleared the situation with these hypotheses and definitions and making use of Huygens's researches into centrifugal force, Newton applied his hypotheses (which, as we have seen, involve Galileo's law of falling bodies) to Kepler's law of planetary motion, $r^3 = kt^2$. The outcome, concerning which we cannot readily supply the proof here, was a curious mathematical result, namely, that, so far as a planet and the sun are concerned, the force of the assumed gravitational attraction between them varies directly as the product of their masses and inversely as the square of their distance apart, that is, $F = \frac{KMm}{r^2}$. The numerator of the right side of this equation is nothing strange. It is merely a restatement of Galileo's findings that force varies with mass. The fact, however, that in measuring gravity the distance between bodies is the other important controlling factor, is the new and surprising situation disclosed by Newton's final generalization, which has come to be known as his "inverse square law." This generalization he now proceeded to try out.

A suitable test was not difficult to find. Newton was aware of the pull of the earth upon a falling body at the earth's surface, which is about 4000 miles from its center. Galileo and Huygens had worked this out. Now if the earth attracts an apple, it must, under Newton's hypotheses, also attract the moon, which is kept from falling because of the resistance produced by an assumed initial motion of its own. The moon's distance from the earth's center had

already been estimated as about 240,000 miles, or sixty times the earth's radius. Newton also knew the force actually keeping the moon in its orbit by the formula for centrifugal force worked out by Huygens. In brief, he knew the pull (F_1) of the earth's gravity at its surface and the pull (F_2) keeping the moon in its orbit sixty times farther away. If his inverse-square assumption held, F_1 should be equal to 3600 (60^2) times F_2. (We omit the intervening mathematical computations.)

This relationship we now know as actually existing, but unfortunately in 1666, when Newton first worked on the problem, the earth's radius had not been accurately measured, a fact not realized at the time. As a result, Newton's deduction test ended in failure and keen disappointment, for with the incorrect figures F_1 did not equal 3600 times F_2. His assumptions, he felt, were wrong. Sixteen years passed before a more accurate measurement of the earth's radius was made. Newton was present when the findings were read to the Royal Society. Stirred to the depths, with his abandoned hopes of sixteen years before revived in fullest intensity, he hurried home to make the calculations with the corrected figures. So great was his agitation that he asked a friend to do the figuring for him. The results accorded fully with his inverse-square hypothesis. Newton's deduction had become a great scientific generalization!

Even then Newton was for some reason reluctant to make his discovery public. It required the efforts of his friend Edmund Halley, the astronomer, to induce him to give publicity to his researches, which were finally published in 1686 in what is still regarded as the greatest single contribution to science, his epoch-making "Principia Philosophiæ."

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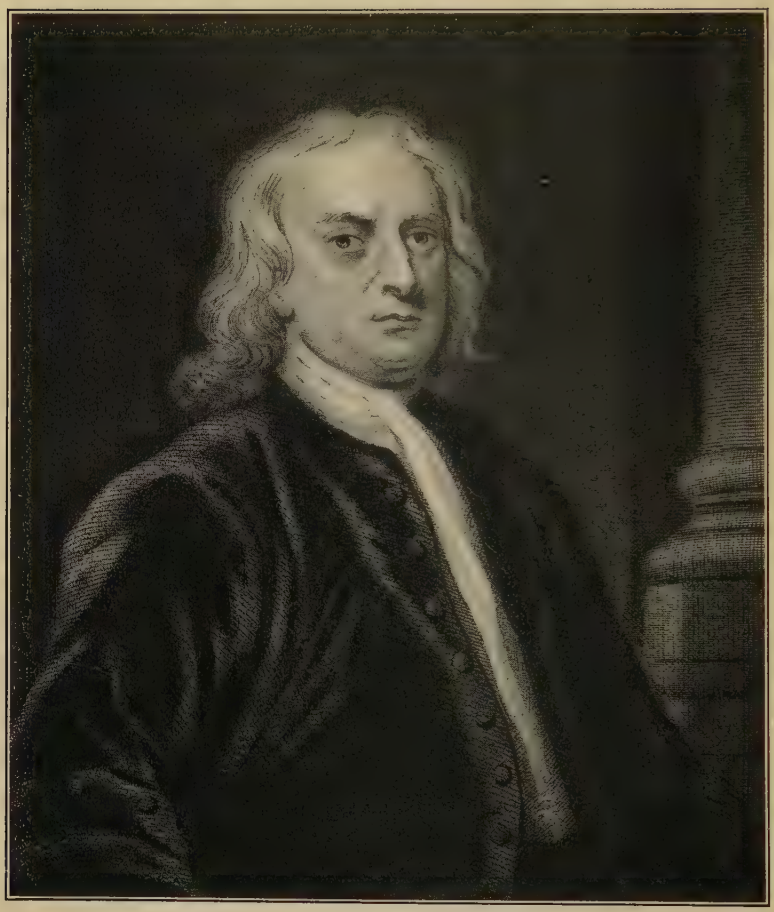


NEWTON

§ 3

Newton's stupendous achievement with respect to gravitation had a revolutionary effect on all science, and especially upon astronomy and physics. In astronomy the result was not to put the subject upon a new basis, but rather to confirm the soundness of the foundation laid down by Kepler and Galileo and to hasten the abandonment of the false theory of vortices put forth by Descartes. Astronomical research took on a new impetus. On the one hand, men of great intellect were drawn into the work of applying Newton's law to the remotest of astronomical observations and of verifying its accuracy. On the other hand, astronomy no longer continued to concern itself primarily with the plan of the solar system. Attention was drawn to other problems.

In physics, the effect of Newton's law of gravitation and its corollaries was decidedly revolutionary. Dynamics, the sub-science of things in motion, was placed upon a firm basis, and with this secure the other branches of physics could develop along constructive scientific lines. For dynamics is fundamental to the rest of physics, just as physics itself is fundamental to other sciences.

The basic character of dynamics was not appreciated in Newton's day. It was not then realized that sound, heat, light, electricity, magnetism, all and each, can be reduced to various kinds of motion. Sound is now perceived as vibrations in the air striking the ear-drum; heat as an agitation of the molecules of a body communicated to us through the sense of touch; light, electricity, and magnetism as vibrations of differing frequencies in the so-called ether. Each of the sub-sciences dealing with these phenomena may now be said to have its own laws of motion, its dynamics; but their developments are recent. In Newton's day very little of these relationships was known, and what was worked out

was due largely to his own achievements in sound and light, in addition to his major contribution to general dynamics. His laws of motion and of gravitation placed physics on an unassailable scientific foundation. Newton's herculean efforts sufficed to break the third Seal of Science.

In what has just been said about the relation of dynamics to the rest of physics, we have once more an illustration of an important theme which permeates this essay; namely, that there is a definite sequence to the unfoldment of the sciences. Without Greek mathematics, without Descartes's additions in analytic geometry, and without the work of other able mathematicians who preceded Newton, the calculus as a tool for analyzing moving forces could not have come into being. Without the calculus and the other mathematical implements, and the laws of terrestrial and celestial motion worked out by Kepler and Galileo, the Newtonian substructure of physics could not have been laid; and, in turn, without physics secure, other sciences could not have been put into place.

That there is a well defined hierarchy to the sciences must now be regarded as an outstanding scientific fact. This does not mean that each science in the sequence must be *completed* before the next one can be established. But it does mean that the *foundation-stones* at least must have been laid before the following science can gain the necessary foothold to place it in turn upon a secure scientific basis.

§ 4

Before returning to the chronological outline of Newton's career, from which we turned aside to take up his contributions to mathematics and dynamics, begun and brought to almost full completion during the two plague years of '65 and '66, we may profitably pause further to examine

another of his major endeavors begun about the same time, and continued as part of his teaching work when he succeeded Barrow as professor of mathematics at Trinity College. This was his work in optics and light.

The nature of these physical phenomena had puzzled scientists from early times. Every physicist of note had grappled with them. Euclid had been a pioneer here, putting forth the idea that light, in coming from the celestial bodies to the earth, travels in straight lines. Ptolemy had gone further and had pointed out that light is refracted out of its straight-line path in passing through various media, as air or glass. The crooked appearance of an oar in water, for instance, is due to the refraction of light in passing from the air into the water. Ptolemy had also noted that the direction of refraction is related to the angle of incidence, which is the angle at which the light-rays strike a medium before passing through. He had calculated how much must be allowed to correct the apparent displacement of a heavenly body from its real position as viewed from the earth. Without such corrections, astronomy would still be weltering in a maze of inaccuracies.

During the Dark Ages the Arabs had advanced the study of light and optics somewhat; but the next really important contributions are found in the "Opticks" of Roger Bacon, wherein he describes magnifying and burning glasses and illustrates diagrammatically how light is refracted and focused in passing through lenses of various designs. He, it will be recalled, also introduced the idea of spectacles to improve vision.

With Galileo the early study of optics had reached its high-water mark in his improved telescope. This was soon followed by the invention of a usable microscope, as we have already had occasion to mention in other connections. Kepler had improved on Ptolemy's methods of calculating

angles of refraction and had paved the way for the later discovery of a definite relationship, for a given medium, between angle of incidence and angle of refraction. Descartes had also contributed to the subject. Then came the brilliant researches of Newton and Huygens.

As early as 1664, Newton began experiments at Trinity to determine the meaning of the so-called phenomenon of colors. That sunlight at times produces colored effects, as in the rainbow or in passing through prismatic glass, had been known for centuries, but no one had worked out the explanation. The result of Newton's researches here was the startling realization that sunlight is not homogeneous but is a composition of seven main colors—red, orange, yellow, green, blue, indigo, and violet—each with a different angle of refraction, which accounts for their being spread out or dispersed in passing through a prism. All these colors put together produce the white-light effect we get from sunlight. Applying his results to the *refracting* telescope, which had been giving color troubles, Newton concluded that this type would always encounter such difficulties and that for the best results a *reflecting* telescope should be used.

Without going into the details of this fascinating field of scientific study, it must suffice to point out that Newton's researches in light and optics paved the way for the giant reflecting telescopes now used in the world's largest observatories and for the invention of the spectroscope, which opened another epoch in scientific development.

The behavior and color composition of light is one thing. Its intrinsic nature is another. What is the character of this light which is refracted at different angles in passing through different media and which can be broken up into seven major colors in passing through a prism? Is it something material? Are particles or corpuscles sent through

space from the luminous source? Or is it something immaterial, like sound, merely a wave-motion in the transmitting medium? These were the next questions to which Newton addressed himself.

He had already demonstrated conclusively that sound has no material existence and that it is the result of vibrations set up in the air, which, striking the ear-drum, cause us to experience the phenomenon called sound. Boyle and Guericke had helped prepare the way for this explanation by showing that in a vacuum, where there is no air, the ticking of a clock cannot be heard.

Newton was fifteen years younger than Boyle and thirteen years younger than Huygens. While Boyle was laughing out of court the notion that nature abhors a vacuum by actually producing one at will with his air-pump, Huygens was putting forth his bold assumption, in an effort to explain the nature of light, that even within a so-called vacuum, and in and through everything else, there is an all-pervasive something which he called the "ether," and upon which, he held, light travels in undulations or waves just as sound travels on air. This famous undulatory theory, which considers light as immaterial as sound, is the one now generally held. It has to-day also received added significance through being used to explain electrical and magnetic phenomena.

In Newton's day, as already indicated, the fact that Huygens had conceived the undulations of light as longitudinal rather than transverse, and the fact that polarization cannot be explained with the longitudinal hypothesis, presented an insurmountable obstacle to the acceptance of the theory. In opposing it, Newton substituted his corpuscular hypothesis, which held that light is composed of tiny particles emitted from the luminous source. Around these two conceptions a historic controversy raged, with Newton

on one side and Huygens on the other. Huygens defended his hypothesis most ably, but the weight of Newton's authority, together with Huygens's death in 1695 and the incorrect conception of the undulatory theory held at the time, turned the scales in Newton's favor. The corpuscular theory came to have the preference until the beginning of the nineteenth century, when a conclusive experiment showed it to be untenable.

Despite the opposing views of Newton and Huygens, they were on the friendliest of terms. Newton had only the highest words of praise for his older contemporary, to whose splendid work in mathematics and physics he himself owed much. Both men contributed prodigiously to the science of physics. It is to be regretted that only the briefest mention of their achievements can be made in these pages.

§ 5

When in 1669 Barrow resigned his chair of mathematics at Cambridge University in favor of young Newton, it was because the latter's genius had already become fully apparent to him. For the next eighteen years, Newton's time was taken up with lectures and research and with the controversies that arose. In 1687, on the eve of the English Revolution, he became involved in a dispute between the crown and Cambridge University. The university had refused to comply with the king's command in a certain matter, and its vice-chancellor was adjudged in contempt. The part Newton played in the subsequent proceedings caused the crown to give way, and as a consequence Newton was elected to Parliament. Later he accepted the post of warden of the Mint of England on terms which did not interfere with his university professorship. His scientific knowledge resulted in a transformation of the coinage of Great Britain

and in his elevation to the position of master of the Mint. This was in 1697. His augmented duties, and the bitter controversy over his theory of fluxions in which he was embroiled soon afterward, now became too much for him, so that in 1703 he resigned his professorship. The same year he was elected president of the Royal Society, and a short time later he was elevated to knighthood. Several years before, France had paid him the tribute of electing him as the first foreign associate of the Academy of Sciences.

At the age of sixty-one Sir Isaac Newton is seen engaged in a routine of duties at the Mint, Parliament, and the court of England. He had become a great court favorite. Yet he had lost none of his interest in mathematics and physics. He was still a power of the first magnitude in the scientific world. A spirit of international rivalry had developed, in which all the great mathematicians of the day took part. One authority would develop a troublesome problem and challenge his contemporaries to work it out. Newton always found a solution without apparent difficulty. On one occasion, the mathematician Jean Bernoulli propounded a most complicated problem which it took Leibnitz six months to fathom. It was then sent to Newton, who solved it in twenty-four hours and published the answer anonymously. Bernoulli, recognizing the master's handiwork, exclaimed on reading the solution, "*Ex ungue leonem!*" Just as the lion is known by his paw, so was the handiwork of Newton manifest. No finer tribute to his genius could have been given than this spontaneous exclamation from one of the premier mathematicians of the day.

For twenty years more Newton's great personal influence continued to make itself felt, but finally the infirmities of old age overtook him, and he died in his

eighty-fifth year. Many glowing tributes were paid to his memory, among which Playfair's eulogy is here selected as an excellent epitome of his work:

> To his important inventions in pure mathematics Newton added the greatest discoveries in the philosophy of nature; and, in passing through his hands, mechanics, optics, and astronomy were not merely improved but renovated. No one ever left knowledge in a state so different from that in which he found it. Men were instructed not only in new truths, but in new methods of discovering truth; they were made acquainted with the great principle which connects together the most distant regions of space, as well as the most remote periods of duration, and which was to lead to future discoveries, far beyond what the wisest or most sanguine could anticipate.

Shortly before his death, Newton himself wrote, in a characteristically modest vein:

> I know not what the world will think of my labors, but to myself it seems that I have been but as a child playing on the sea-shore; now finding some prettier pebble or more beautiful shell than my companions, while the unbounded ocean of truth lay undiscovered before me.

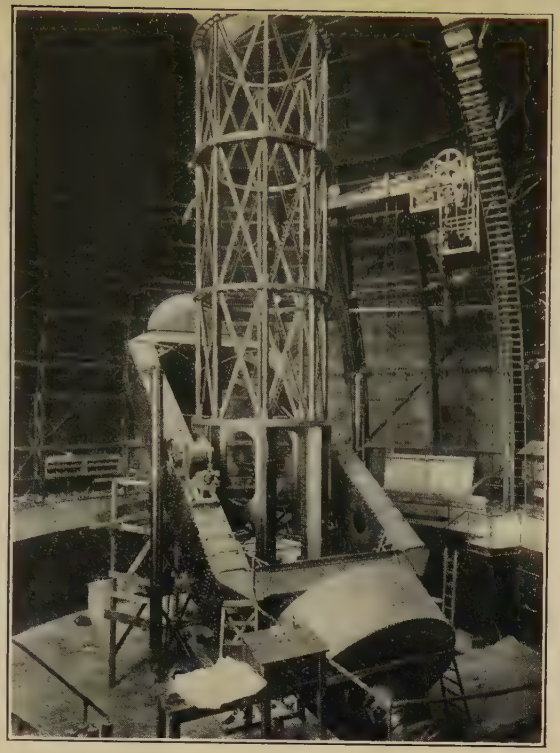
True it was that an unbounded ocean of truth lay beyond; yet Newton more than any other one man provided the chart and compass for its successful navigation.

§ 6

What the scientific renaissance of the seventeenth century accomplished may now be briefly summarized.

(1) It was ushered in by the establishment of astronomy as a science and the breakdown of the authority of the written word. Galileo, Kepler, Gilbert, and Harvey are the prominent figures here.

(2) Science and its methods became widely known



GIANT TELESCOPES

MT. WILSON 100″ REFLECTOR

Largest in the world. Mirror (8 1/3 ft. in diameter) situated at base to the right.

HARVARD 16″ REFRACTOR

Fitted up for photographic purposes and mounted with accessory telescope

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through the poignant writings of Francis Bacon and René Descartes. Direct observation of nature and careful experiment took on a scope theretofore undreamed of. And just as happened on a smaller scale in Aristotle's day, speculative theories, once the rebirth of scientific interest came, were advanced on every hand regardless of whether they were carefully considered or not. The methods of science became more fully understood, but that there is a sequence to the unfolding of scientific knowledge no one as yet surmised. It was not then known that a formulation of the fundamental laws of physics had to precede the founding of chemistry as a science, that an understanding of chemical principles had to come before geology and biology could be securely established, and that biology in turn is fundamental to psychology. It was only natural, therefore, that many false theories should be advanced to account for chemical, geological, biological, and psychological phenomena, at the same time that the substructure of physics (the next in the sequence after mathematics and astronomy) was being completed. And, of course, the new false theories had to be broken down later just as the false theories of the ancients were, except that the process had become easier because of the wider adherence to the inductive method.

(3) At the high-water mark of the period physics was placed on a solid basis at the hands of the incomparable Newton and his co-workers. The stupendous sweep of this achievement has just been indicated. In addition to these major accomplishments, the groundwork was being prepared by Boyle and others for the subsequent establishment of chemistry; the invention of the microscope and the brilliant researches of men like Malpighi were opening up a new era for nature study, so that after further assistance from physics and chemistry, the sciences of geology and biology could perfect their structures; and the relationship

between psychology and metaphysics was being elucidated, the resultant discussion continuing in a highly speculative way until (the physiology and anatomy of the brain and nervous system made clear by biological advance) the foundation-stones of modern psychology could finally be laid down.

CHAPTER VII

EIGHTEENTH-CENTURY SCIENCE: THE RISE OF CHEMISTRY

§ 1

NEWTON'S achievements, as has been intimated, produced an upheaval in the scientific world. His discoveries were so far-reaching and the controversies engendered so embittering that the result was frenzied activity in some quarters, almost complete stagnation in others. For the greater part of the eighteenth century, science was endeavoring to grasp and digest the meaning of his accomplishments.

The eighteenth century also witnessed social and political changes of significance, though the tactics used in these fields continued to be those of the primitive savage rather than those of civilized man. By the time the century opened Spain and Holland had risen to positions of political eminence and fallen from them again, and England was displacing France as first among the nations. Sweden had secured a controlling position in the North; but Russia now emerged from obscurity, under the leadership of Peter the Great, and before the first quarter of the century had passed had forced Sweden to surrender a considerable part of her possessions. Several decades later another power rose to ascendancy in Europe, Protestant Prussia, which, assisted by England, succeeded after a seven years' war in repulsing both Catholic Austria and royalist France. England, politically and religiously free, was now supreme on the seas, had wrested North America from France, and had extended her influence to India.

But England was to lose her American colonies, who could not quite swallow the idea of paying for the mother-country's foreign wars and who declared themselves free and independent in 1776 under a form of government which dispensed with kings and nobles entirely. Royalist France had assisted democratic America, but a new temper was present in this aid—something quite apart from her hostility to England. In 1789 the new spirit burst its bonds, and France, in the course of a bloody revolution, renounced her kings and became a republic. At the same time autocracy in Prussia, Austria, and Russia strengthened itself at the expense of prostrate Poland, which was dismembered till it ceased to exist.

The kings of Europe had risen to supreme power as the papacy declined. They had had their own way for a considerable period, and France under Louis XIV (1643-1715) had been the complete embodiment of monarchy by divine right. But this king and his successors disgraced absolute monarchy irretrievably and permitted proud France to be mortified. The day of reckoning came in the Revolution of 1789. In alarm, the kings and princes now flew to arms and began a concerted campaign against the French republicans "for the safety of their crowns." Harassed by enemies on every side, France nevertheless held her own and as the century closed not only had expelled the Prussian, English, Austrian, and other invaders but under young Napoleon had conquered Italy. Immediately afterward she concluded a peace (1802) which actually forced the nobles of Europe to recognize the political supremacy of the Republic in Continental affairs.

Had Napoleon only stopped there! But the temptation was too great. His ambition to wear a crown and to lord it over Europe were soon to prove his undoing and to hurl France once more into the eager arms of monarchy.

Politically, Europe continued, as she still to a considerable extent continues, to play the game of duplicity and brute force, with the lives of human beings as her pawns. In science, only one spirit had been manifest from the beginning, the fearless, unbiased search for truth that knows neither race nor creed. While in the one arena eighteenth-century Europe continued her intrigues and bloodshed, in the other arena augmented facilities for publication and the multiplication of scientific societies were providing for a rapid interchange of ideas and enabling scientists to keep in touch with progress in foreign countries without the necessity of personal contact. Court and church finally came to regard scientists with indulgence and even respect, unless the scientists carried their convictions directly into politics or ecclesiastical affairs. This was a decided advance over the intolerance and opposition of the Galilean period.

The scientific upheaval following Newton made itself felt first in mathematics, astronomy, and physics, and toward the end of the century in the transformation of chemistry into a science. As the period closed, like waters gathering force from many tributaries previously shut off from the main stream but finally breaking through the obstacles, a great river of scientific activity burst upon the world with inundating force, bringing in its wake a tremendous fertility of discovery.

§ 2

The historic controversy between Newton and Leibnitz over the calculus, and the relative freedom from social and political disturbance in England, isolated that country during the eighteenth century from the mathematical activity of the Continent, where the more effective calculus notation of Leibnitz was uniformly followed. Despite important English achievements that might be mentioned, especially

those of Maclaurin of Scotland, who systematically developed the fluxional calculus, and whose work was characterized by the great Lagrange as "comparable with the finest and most ingenious work of Archimedes," the outstanding mathematical advances of the period were made on the Continent.

In Switzerland, the Bernoullis, a family of gifted mathematicians and teachers, trained their pupils thoroughly in the Leibnitzian technique. At the same time the Frenchmen Clairaut and d'Alembert developed so-called differential equations as an outgrowth of the calculus and applied them to a more accurate determination of the motions of the moon, to the variation in the earth's gravity due to its ellipsoidal rather than completely spherical shape, and to the principles of wave motion as produced by sound and other physical phenomena.

Outstanding among the Continental mathematicians of the second half of the eighteenth century were Euler, Lagrange, and Laplace. Leonhard Euler (1707-1783), a pupil of the Bernoullis, recast the whole science of mathematics in his excellent treatises, did notable work in formulating equations to represent troublesome problems in the motions of rigid bodies and of fluids, and completed the mathematical theory of the moon's motion with which Clairault had struggled and for which Newton had done the spadework. Euler's industry was prodigious, despite failing eyesight which ultimately led to total blindness. The present mold into which college texts on algebra, analytical geometry, and the calculus are cast had its origin very largely in his penetrating and clarifying activity.

Joseph Louis Lagrange (1736-1813), introduced to mathematics at the age of nineteen, solved within two years thereafter a problem in the calculus that had been in dispute for half a century. Such was his genius. At twenty-five he

had hardly a rival, and during the next fifty years there was no phase of pure and applied mathematics on which he did not leave an impress and which he did not enrich. He had an unusual facility of expression and a unique power of analysis, as a reading of his "Mécanique Analytique," one of the landmarks in mathematical progress, will serve to demonstrate.

Pierre Simon Laplace (1749-1827), the third of this able trio, was preëminently an applied mathematician, whose chief interest lay in solving physical, astronomical, and geological problems. He founded the modern school of mathematical physicists, worked out some of the more important of the principles governing the motions of the moon and other satellites, and was the first to give a clear scientific explanation of the origin of the solar system. His famous nebular hypothesis, that the planets were thrown off by the sun out of a primordial nebula and under a contraction produced by the force of gravity, held the field completely for more than a century and though now somewhat modified still holds the field to-day. His "Mécanique Céleste" is a landmark not only in mathematics but in astronomy and geology as well.

Thus, throughout the eighteenth century and beyond, the new world, opened up to mathematical analysis by the invention of the calculus, came to be explored by intellectual giants of the first order. It is not within the province of this book to develop the technical details of their exploratory effort. Suffice it to say that no present-day student of the calculus, of differential equations, and of higher mathematical analysis can fail to appreciate the revolutionary effect of the labors of the men we have so very casually just reviewed, upon all branches of scientific inquiry from their day onward, and especially upon progress in the fields of astronomy, physics, and chemistry.

§ 3

In turning to further eighteenth-century advances in astronomy, it is well to recall once more that the foundations for this science had been laid down by Kepler and Galileo before the advent of Newton. Kepler had discovered the three laws of planetary motion and had done notable work on astronomical tables, on the behavior of comets, and on the sun's motions. Galileo had perfected the first usable telescope, had pointed out that the moon has mountains and valleys and that the sun has spots, had indicated that the planet Jupiter is attended by several moons, and in general had disproved the deeply rooted cosmographical prejudices of his age.

Newton, in addition to his momentous cosmographical and physical generalizations, had explained the ocean tides as in part the result of the gravitational pull of the moon, had proved that the earth is not a perfect sphere but an ellipsoid, and had clarified a number of other astronomical observations previously a puzzle. After Newton, the famous observatories at Greenwich and Paris were built and the modern era of astronomical progress began.

With the acceptance of Newton's results, astronomy, as has already been intimated, received a new impulse in two directions: one, in applying his gravitational law to the remotest and minutest of astronomical observations to verify its complete accuracy; the other, in opening up the study of new problems, the plan of the solar system now coming to be regarded as completed. With both these developments the name of William Herschel is intimately connected. Other notable names are also closely associated with the astronomical advances of this period, and these will be mentioned presently, but Herschel symbolized the post-

Newtonian astronomical spirit so well that his life and work merit more than casual consideration here.

Frederick William Herschel (1738-1822) was a musician and the son of a musician. His father had been interested in astronomy and had owned a small telescope, through which William scanned the heavens. The boy's first view of the night sky "set the current of his life and fired him with the ambition to look farther into space than ever human being did before him." This ambition he realized.

All the education given William was musical. The theory of music, however, involves a study of mathematics; and for an ambitious young man it was an easy step from this point to optics and astronomy. At the age of thirty-four, in 1772, we find him in England, whither he had emigrated from his home in Germany. He was supporting himself in his profession. With him resided a younger brother, also a musician, and a sister Caroline, who had come there ostensibly to study music, but who soon found that she was being trained to help her older brother in his astronomical work.

Herschel quickly recognized the advantages of the Newtonian reflector over the Galilean refracting telescope. With the reflecting type, the rays of light from a heavenly body fall upon a concave mirror and are then reflected and focused in a convenient way for observation. The important part is the mirror. As the price of a good one was beyond Herschel's means, he decided to become his own optician. Both he and his brother possessed good mechanical skill, so that together, during a dull musical season, they set to work converting their drawing-room into a carpenter shop and, much to the dismay of Caroline, who was the acme of neatness, and who was keeping house for the three, installed a lathe in one of the bedrooms. Caroline soon caught

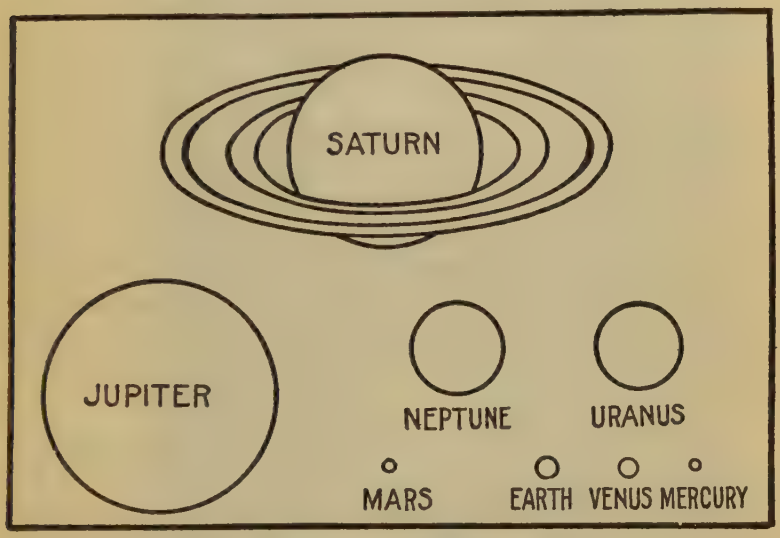
the scientific spirit, however, and became a most valuable astronomical assistant.

After some two hundred partially successful attempts, the Herschels perfected a magnificent reflector. The story of their perseverance in the painstaking work of polishing mirrors, requiring most tedious and sustained effort, forms a scientific classic which is well worth the reading. During a period of sixteen hours, on one occasion, the elder Herschel's hand never left the mirror he was polishing. After six years of such experience, rushing home after a brilliant musical performance to the monotonous grinding and polishing of reflectors, he was able to produce a telescope that was the equal of any ever made.

Long before this he had at intervals scanned the heavens with the less perfect instruments he had completed. In 1775 he checked up on every known star in the skies. His experience in this survey served chiefly to convince him that he needed a still better reflector. By 1781 he had made something like 430 mirrors of gradually increasing size. It was during this year, in making a second review of the heavens with his largest reflector, that his attention was attracted by a new star, one that had never before been catalogued. He noted its position at various times and thought it behaved like a planet. He cautiously described it as a comet; but the scientific world was quick to appreciate the value of his discovery, whether comet or planet, and he was forthwith elected a fellow of the Royal Society and afterward awarded the famous Copley medal. Lexell of St. Petersburg later proved that Herschel had truly discovered a new planet, about nineteen times as far from the sun as the earth is, and in due time it was named Uranus. This was the first addition to the sun's planetary family since the ancient Greek period.

It was soon observed that the movements of Uranus did

not seem to conform to Newton's law. This apparent discrepancy was not explained till the middle of the next century, when two astronomers, one in England and one in France, simultaneously calculated that the discordance must be due to the gravitational pull of still another planet, and successfully predicted where the new planet would be found.



RELATIVE SIZES OF THE PLANETS

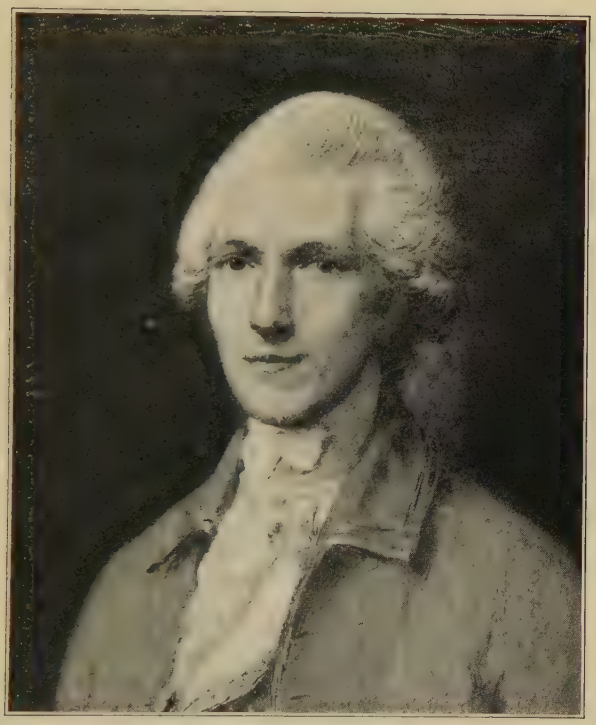
Thus Neptune was discovered in 1846 on the first night a search was made for it, and Newton's law was once more vindicated, this time in a most spectacular way.

During the eighteenth century a host of astronomers were engaged in testing out Newton's generalizations. Nor did the motions of Uranus furnish the only apparent discrepancy that arose. Other observations that did not seem to conform were certain irregularities presented in the motions of the moon, which have only recently been satisfactorily cleared up in accordance with Newton's laws, and

certain fluctuations in the orbital movement of the planet Mercury, which no recourse to Newton's equations could seemingly elucidate, and which remained unexplained until Einstein provided a new formula.

Turning from the testing of Newton's laws to the special astronomical problems that were attacked after his time, we find that one of the most important has been to discover what motion, if any, the so-called fixed stars have. Here, again, Herschel did notable work. So did his older contemporary, James Bradley, who succeeded Edmund Halley as astronomer royal of England, and who in 1755 constructed a star-catalogue, by far the most accurate up to his time. Twenty centuries before Bradley, Hipparchus of Alexandria had constructed the best previous catalogue of the stars. It took the upheaval following Newton to produce something better; and before any seeming motion among the stars could be satisfactorily investigated, this more accurate plotting of their positions had to be carried out.

In 1718 Halley had carefully catalogued the southern stars and had noted apparent motions in several of them. About the middle of the century, Bradley at Oxford and Mayer at Göttingen suggested that these seeming motions might be due to a movement of the sun itself. Herschel followed up these suggestions, after his discovery of Uranus, and concluded that the whole solar system, the sun and all its planets, is moving as a unit in the direction of the constellation Hercules. Later researches confirmed Herschel's conclusion and indicated that the speed with which the solar system is thus moving is about seven hundred miles an hour. More recent experiments, conducted by Professor Miller on Mount Wilson in 1925, seem to suggest that this velocity is nearer seventy-five hundred miles an hour and that the direction is slightly different



COUNT RUMFORD

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from that found by Herschel; but Miller's experiments will need further verification before they can be generally accepted.

Closely related to the seeming motions of the stars is the question of their distances from the earth. This problem has engaged the attention of astronomers of every age. So soon as it had become apparent that the sun is not intrinsically different from the rest of the heavenly bodies, the great distances of these from the earth, in comparison with the sun's distance, came to be vaguely appreciated. Yet no one had any conception of the incredible distances of the stars in space until relatively recent times. Stellar distances are now measured in "light-years." Figure it out! Light travels 186,000 miles a second. How far does it travel in a minute, in an hour, in a day, in a week, and finally in a year? The last of these is the staggering and incomprehensible distance covered by the term "light-year." And twenty light-years away from the earth is an ordinary star distance! Some stars are 100,000 light-years away.

To measure stellar distances requires instruments of great precision, and such instruments were not in existence in Herschel's day. It was only after the perfection of the heliometer and the spectroscope, products of the physics of the next century, that the necessary accuracy was obtained. Bradley, the most accurate observer up to his time, had tried unsuccessfully to measure star distance with the instruments then available, and in his attempt had made an unexpected and important discovery. He had detected the so-called aberration of light, which is a phenomenon occasioned by the movement of the earth through space, and which seemingly displaces the stars from their true positions. This is quite apart from the displacements caused by refraction.

Herschel also made an unsuccessful effort to measure

stellar distance and likewise hit instead upon a discovery of importance. He had chosen two stars close together, one brighter than the other, as a basis for his observations, little thinking that they were in any way related. On examining them closely he noticed to his astonishment that one revolved about the other. Observations of other sets yielded the same results, and subsequently thousands of such pairs of binary stars have been located. It has been found, also, that their motion accords with Newton's gravitational law. They revolve one about the other as a result of their mutual attractions.

Herschel's early observations, as has been indicated, were made under great handicaps. He gained his livelihood as a musician, and he was eminently successful in his profession; but his heart was elsewhere. It was not till after his discovery of Uranus that he was able to devote himself undividedly to the study he loved. When his achievement was brought to the attention of the king of England, the post of astronomer royal was offered him, together with a grant of the equivalent of ten thousand dollars for the construction of a giant telescope. Herschel eagerly accepted, despite the fact that his income was at first much smaller than it had been during his musical career. He was now completely satisfied. With undivided attention and improved instruments, he kept steadily on with his researches. He catalogued eight hundred double stars and two thousand nebulæ!

In 1788, at the age of fifty, Herschel married; and his only son, John, born four years later, also became a famous astronomer. Nor was the work of Herschel's sister Caroline in vain. She herself discovered eight comets and was awarded the Royal Astronomical Society medal when seventy-five years old. The romance of the Herschels provides fascinating as well as instructive reading. Nowhere, pos-

sibly, can one get the spirit of eighteenth-century science better than in a study of their lives and work.

With the century's close, Newton's inverse-square law had been generally accepted by astronomers, and the special problems of astronomy had been more or less clearly delineated. Besides the study of stellar motions and distances, which had led to more accurate star-catalogues and to the discovery of binary systems of stars, of the aberration of light, and of the solar system's motion through space, other problems, such as the origin of the solar system, the more careful examination of the sun and its spots, and the determination of the size and chemical constitution of the stars, had also been launched. But progress in the solution of these problems had to await newer instruments, which the sciences of physics and chemistry forged in the nineteenth century. Regarding Laplace's theory of the origin of the solar system, more will be said in the following chapter when eighteenth-century advances in geology are discussed.

§ 4

In physics, the chief concern of the century consisted in a further testing of Newton's laws as applied to such fields as electricity and magnetism. At the same time, important progress was made in clearing away a false theory having to do with so-called imponderables, which to a large extent was enmeshing the whole subject in misconception. It was not, however, until after the beginning of the nineteenth century that this theory suffered a complete collapse and the way was opened for a rapid advance in physics.

In Newton's day there were a number of imponderables, —figments of the imagination manufactured to explain certain physical phenomena. Newton himself added to the list, in his "corpuscle" of light. Besides this, the "caloric" imponderable was supposed to be something a body drew into

itself when heated and lost when cooled; the "phlogiston" imponderable, something a body gave off when burning; and the "effluvia" imponderable, something that occasioned the behavior of electricity.

In light and optics, the acceptance of the imponderable theory created so many obstacles to progressive research that for a time after Newton almost complete stagnation resulted. It was not until two noted physicists at the beginning of the nineteenth century took up their cudgels for Huygens's wave theory, and scrapped the idea of light corpuscles, that the difficulties melted away and a real advance took place.

A similar situation developed regarding heat. The theory that caloric is taken on and given off when a body is heated and cooled, and that phlogiston is lost when a body burns, originated in the seventeenth century. Various fantastic suppositions as to the properties of caloric and phlogiston were put forth, until the whole subject of heat was almost hopelessly entangled. Galileo, Francis Bacon, and Boyle had suggested that heat might be a mode of motion, yet no one for a century or more took these suggestions seriously. Heat was generally regarded as a material substance, and so was fire.

It remained for a most remarkable American soldier of fortune, Count Rumford (1753-1814), to advance the subject further. Born under the name of Benjamin Thompson in Woburn, Massachusetts, this early American became eminent not only as a scientist but also as exemplifying in a very practical way the brotherhood of all men. Virtually forced into the ranks of the Royalists during the Revolutionary period because of the jealousy of fellow-officers in the colonial militia, who resented being outranked by a mere lad, he left for Europe, after receiving his scientific training, and rose rapidly to prominence in the scientific,

social, military, and political life of three nations. In England he became under-secretary of state, founded the Royal Institution of London, and was elevated to knighthood. In Germany he was created Count Rumford, and served as privy councilor, chief of police, and minister of war. He so revolutionized social conditions in Munich, that, though he was a foreigner and a Protestant in a Catholic community, the poor of the city spontaneously turned out in a body to offer up public prayers for his recovery during a serious illness. In France he married the widow of the distinguished French chemist Lavoisier and became a close friend of Napoleon. By this time the czar of Russia was urging him to make his home in St. Petersburg and President Adams was offering him the posts of superintendent of the Military Academy and inspector-general of the artillery. Rumford never lost his love for his native land, despite the jealousies that had driven him from her shores. He left his fortune to Harvard, where under privation and difficulty he had received his training in science.

It would seem that such an active career as Count Rumford's would leave little room for scientific pursuits. And yet his whole mature activity represented a colossal experiment in science. Whether in his project to survey the White Mountains, which never materialized, or in his work in the army, where he experimented upon the action of gunpowder and projectiles and upon the nature of heat, or in his introduction of improved methods of horse breeding, or in his social experiments of one kind and another, every new experience seemed to present to him an additional opportunity for research and experimentation. The whole world was Rumford's laboratory.

But we must return to the eighteenth-century progress in physics. While engaged in boring cannon at a military workshop in Bavaria in 1798, Rumford began to suspect

that heat has no material existence; whereupon he decided to put the caloric theory to a test. A body taking on heat should gain in caloric. Rumford weighed the cannon and the boring tool before and after the borings, at which an enormous quantity of heat had been generated, but there was neither loss nor gain in weight. Apparently caloric did not weigh anything. He tried to "exhaust" the caloric by continuing the boring operations for a considerable period of time; but he simply got more and more heat, which would seem to indicate that caloric was inexhaustible. He tried the experiment under water, to make sure that the heat did not come from the air, with no variation in the results. Finally he arranged a contrivance for drilling into a piece of brass under water, and by means of the heat produced in the boring operation, much to the surprise of the by-standers, brought the water to the boiling-point. His conclusion was that heat is caused by the friction of one body against another and that caloric is a meaningless and gratuitous assumption. By this time the chemists had demonstrated that phlogiston is likewise meaningless. Rumford felt persuaded that he would live to see "caloric interred with phlogiston in the same tomb."

A co-worker of his, Sir Humphry Davy (1778-1829), continued these experiments at the Royal Institution. Davy introduced two pieces of ice into the receiver of an air-pump, the interior of which was then exhausted to produce a vacuum; and, keeping the whole apparatus at a temperature below freezing, he caused one piece of ice to be rubbed against the other. Despite the low temperature and the vacuum, the ice melted under the rubbing; and since the possibility that the heat came from either the material itself or from the surrounding medium had been rigidly excluded by the very nature of the experiment, Davy also came to Rumford's conclusion. As he expressed it, "Friction

causes vibration of the corpuscles of bodies, and this vibration is heat."

These conclusive experiments, and a strong attack on the imponderable theories by another noted scientist at about the same time, should have been sufficient to mark the obsequies of caloric. It was not until the middle of the nineteenth century, however, that the interment which Rumford expected to witness actually took place.

Davy was eminent not only as a physicist but also as a chemist, and his inspiring lectures at the Royal Institution attracted wide attention. It was he who discovered that nitrous oxide, popularly called laughing-gas, can be used to produce anesthesia; and his experiments in electrolysis and other branches of electrochemistry, as we shall have occasion to amplify later, were of even greater import. In addition, Davy discovered the electric arc, so important for lighting purposes to-day, and invented the miner's safety-lamp, the importance of which in preventing disasters from underground explosions can hardly be overestimated. Davy and Rumford were among the most brilliant and picturesque of the notable figures who throughout the ages have advanced the cause of science.

Despite reliance upon the imponderable effluvia in connection with the study of electricity and magnetism, considerable eighteenth-century advance is to be recorded in these fields. So rapid was progress here, in fact, that effluvia was consigned to its last resting-place in the limbo of discarded theories before the century closed. It will be recalled that William Gilbert, at about the beginning of the seventeenth century, did the pioneer work in these branches of physical science. He was the first to draw a sharp distinction between electrical and magnetic phenomena, and it was he who cleared away the weird notions clustering about them before his time, even though he invented effluvia as a sub-

stitute theory. He had demonstrated that goat's blood and garlic and melancholy and seduction, and all the rest of the hocus-pocus attaching itself to the idea of magnetic attraction, were so much nonsense. He had shown that the earth is a giant magnet and accounted for the north and south affinity of the compass on that score. Yet his results were too inconclusive and also too radical for ready acceptance in his day. More than a century passed before his pioneer work was followed up.

Gilbert had roughly differentiated between what he called "electrics" and "non-electrics," assuming that some bodies like resin or glass can be electrified by friction, as a cat's fur is electrified in cold dry weather, and that other bodies cannot be thus electrified. Had he known the meaning of electrical "conductivity" and "insulation" he would have been able to go further and say that all bodies can be electrified by rubbing, but that some lose their electrification immediately unless insulated, while others hold their electrification for a considerable time. This more accurate description of the phenomena Gilbert originally observed and experimented with was given in the early part of the eighteenth century. Materials now came to be grouped as "conductors" and "non-conductors," the former being such materials as copper or other metals from which electricity tends to "flow off" immediately, and the latter being those materials which "hold on" to the electricity. If a conductor is covered with a non-conductor, as a copper wire is covered with rubber, it is said to be insulated, for the electric charge is thus prevented from jumping from the side of the wire. The distinction between conductors and non-conductors was an important forward step in the understanding of frictional electricity (electrostatics).

After the establishment of the principles of conductivity and insulation, it was found, in an attempt to electrify water

in a bottle, that electrification by friction can be intensified, that the original charge can be increased and the whole discharged at once. This is the principle involved in the action of the so-called Leyden jar, and the scientist who discovered it, and experienced unexpectedly the shock of the intensified discharge, exclaimed that he "would not take another for the kingdom of France!" But other experimenters were less timid, and soon the Leyden jar was being widely exploited. Shows were arranged by traveling performers before kings and their courts; and many were the amusing incidents connected with such demonstrations, when austere monks or stately courtiers, induced to join hands for an exhibition of the Leyden jar's powers, suddenly jumped into the air or broke away from the group as the circuit of bodies was closed and the jar discharged its stored-up electrification. Nor could most of the participants be persuaded to try the experiment again! To-day every high-school laboratory has this piece of apparatus, and nearly every youngster has tried its powers.

The Leyden jar and its surprises created a sensation and spurred research in electrostatics, the outstanding name in the eighteenth-century progress that followed being Benjamin Franklin, the first great American man of science. Franklin (1706-1790) was born in Boston, his father having emigrated to the American colonies from England. The fifteenth of seventeen children, Benjamin had few opportunities as a child. He was apprenticed at an early age to an older brother in Boston as a printer, but, not liking the arrangement, he left by ship for New York. Finding no work there, he went to Philadelphia, where he arrived penniless. His active mind and industry, however, soon overcame every obstacle. In 1729, at the age of twenty-three, he had obtained control of a newspaper and was laying the foundation for an outstanding success as a news-

paper man and writer. At the age of forty he had become interested in frictional electricity and had begun the experiments which were to rank him among the illustrious men of science.

In 1747 Franklin put forth his famous "one-fluid" theory of frictional or static electricity, which was quickly accepted throughout the scientific world, and which was retained until very recent times. This theory holds that all bodies possess electricity but show no sign of it unless by some means they receive a surplusage, when they may be said to be "positively charged," or lose some of their normal portion to other bodies, when they may be said to be "negatively charged." This simple explanation suffices even to-day to elucidate all ordinary static electrical phenomena.

After the enunciation of the one-fluid theory, Franklin turned his attention to the meaning of lightning. In experimenting with the Leyden jar, he had made use of pointed rods for "drawing off and throwing off the electrical fire," as he expressed it, and he had noticed the remarkable resemblance between the Leyden jar discharges thus effected and the phenomenon of lightning. In his own words, "Electrical fluid agrees with lightning in these particulars: giving light; color of the light; crooked direction; swift motion; being conducted by metals; crack or noise in exploding; subsisting in water or ice; rending bodies it passes through; destroying animals; melting metals; firing inflammable substances; sulphurous smell."

Satisfied that lightning and static electricity are identical, Franklin determined upon his celebrated kite experiment to see if he could draw down the lightning along a silken string attached to the kite. His success in this daring and startling experiment is common knowledge. It gained him universal recognition and led to the invention and installation of rods on tall buildings to attract and discharge the

lightning where otherwise it might strike the buildings and do damage. Franklin's discovery, one of the great accomplishments of science, won him honorary doctors' degrees from leading British universities and his election as a fellow of the Royal Society.

After these scientific achievements and the invention of the Franklin stove, which is still widely used, this great American entered the arena of statesmanship. Every schoolboy knows of his distinguished service as a member of the Continental Congress, as a signer of the Declaration of Independence, as envoy of the new nation to Europe, as chief executive of Pennsylvania, and as a member of the convention which framed the Constitution of the United States. Franklin had passed eighty when that memorable convention was called, but his great mental powers were unimpaired, and he fought energetically for the constitution in the face of the turbulent opposition which arose. A truly remarkable man in numerous respects, his life and works have furnished an example for many.

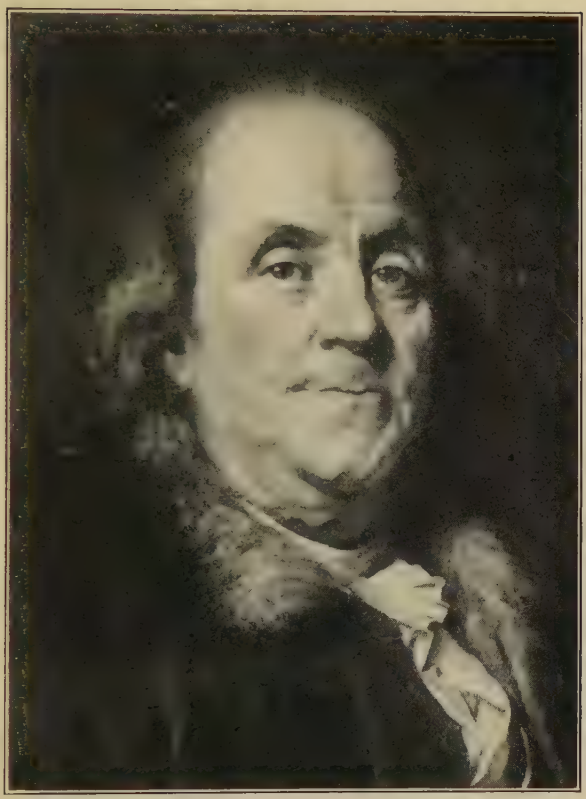
As a result of Franklin's foundation work in electrostatics, a number of noted contemporaries applied the principles of mathematics and dynamics to electrical and magnetic attractions and repulsions, proving Newton's inverse-square law to hold good there also. Among the important names here are those of Coulomb and of Cavendish, the chemist. The contributions of Franklin and these two coworkers helped materially in bringing about the quick abandonment of the effluvia imponderable.

Toward the end of the century, the way was also being prepared for the discovery of "current" electricity and the establishment of the science of electrodynamics. The meaning of current electricity, the kind produced by dry and wet cells and by dynamos, and carried through wires (or even without them in radio transmission) for electric lighting,

bell-ringing, and other purposes, is now known to every household. It is difficult to appreciate that such knowledge is very little more than a century old and that the important electrical inventions are hardly more than fifty years old.

The discovery of current electricity was made at the very end of the eighteenth century by Alessandro Volta, a noted Italian scientist, after whom the volt is named. Volta, who was a biologist as well as a physicist, had been drawn into a controversy which stirred the whole scientific world because of the claim of a fellow-countryman and scientist, Luigi Galvani, that he had discovered electrical energy in the leg of a dead frog. Galvani insisted that the electricity was produced by the nerve of the frog's leg; Volta suspected that it was produced through the action of a copper hook and a piece of iron with which the frog's leg was in contact. He had previously noticed that a peculiar metallic taste results when gold and silver coins are placed end to end on the tongue, and this led him to the belief that some kind of unusual action goes on when two dissimilar metals are brought in contact in the presence of moisture. Following up this clue, Volta made a number of experiments. In 1800 in a letter to the Royal Society he not only proved his case against Galvani but in addition presented his invention of what at once developed into the so-called Voltaic cell, to-day known as the wet cell or battery. Out of this important piece of work the great advances in current electricity and of electromagnetism in the nineteenth century were to come. To the static or frictional electricity known from ancient times had now been added a new and much more important kind, a kind that "flowed" constantly, instead of discharging itself immediately in one spark, a kind that was destined to become a most useful handmaid in every household, store, and factory.

Besides the epoch-making discovery of current electricity,



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to sum up this period of physical advance, the eighteenth century had witnessed important progress in the field of electrostatics, in the application of Newton's inverse square law to electrical and magnetic forces, and in the abandonment of the imponderable effluvia. Imponderables were still involving the fields of light and heat in misconception, although some advance in clearing heat of false theories was evidenced, and additional progress will be indicated as the eighteenth-century developments in chemistry are examined. It was in the latter field, as suggested at the beginning of this chapter, that the outstanding scientific achievements of the century occurred.

§ 5

Chemistry, which studies the constitution of matter, the reactions between elementary substances, and the influence upon chemical structure of weight, temperature, pressure, and other physical forces, did not begin as a science until near the close of the century here under review.

Two things were essential before chemistry could emerge. First, physics had to make clear the meaning of important physical forces, such as weight, temperature, and pressure, before their effect upon the constitution and composition of matter could be determined. In this connection physics had also to devise certain tools, such as the balance, the thermometer, the vacuum-pump, the spectroscope, the electric furnace, and the mechanism of electrolysis which Davy discovered. Without such tools chemistry would have been unable to proceed. Secondly, certain false theories, tied up with the practices of alchemy, and with imponderables again, had to be swept away.

When Newton completed his work physics had provided sufficiently clear ideas and adequate tools for the needs of chemistry, but many misconceptions were still hampering

progress. Gilbert and Boyle had cut away the worst of the underbrush of false theorizing regarding matters chemical; and Boyle, in his clear analysis of atmospheric behavior and of the meaning that should be ascribed to "elements," had indicated the way of approach to scientific chemical knowledge; yet in the eighteenth century, here as elsewhere, the theory of imponderables shut out the light of truth for a while longer. Regarding the imponderable caloric, mention has already been made. While Rumford and Davy were trying to break down misconceptions as to the nature of heat, other investigators were struggling with false ideas regarding the meaning of combustion.

To enable chemistry to advance, the imponderable phlogiston was the ghost that had to be laid. That a substance when burned takes on a new form was known from earliest days, and various explanations of combustion had been attempted from time to time. We now know that burning or combustion, as of coal or wood, involves two things. On the one hand, there is an escape of heat; there was never any misunderstanding on this score, although the *nature* of the escaping heat energy was one of the puzzling questions of the eighteenth century. On the other hand, in ordinary combustion, oxygen from the air is united with the burning substance and forms a compound, the weight of which is greater than before by an amount equal to the weight of the added oxygen.

The phlogiston theory misconstrued this whole process. In fact, it reversed it. The escaping heat, which we now know is immaterial in character, was regarded as the fiery imponderable phlogiston, which was supposed to be possessed of weight, and which left a body as it burned and entered a previously burned body to "resurrect" it again. The net result of combustion, therefore, was presumed at first to be a loss of weight, not a gain. Nor was

there any realization that oxygen has something to do with the burning process. In the early part of the eighteenth century, oxygen was completely unknown. It had not yet been separated from the other gases contained in the atmosphere.

The first doubt of the validity of the phlogiston theory occurred when it was observed that after combustion the burned substance weighs more than before. Joseph Black (1728-1799) was one of the first to detect this discrepancy. He also discerned what he thought was a strange kind of air. He called it "fixed air" and ascertained some of its properties. We now know his discovery to have been carbon dioxide gas. Black's achievements were exceedingly significant, since they focused attention upon two critical points; namely, the untenableness of the phlogiston theory, and the fact that air is not homogeneous. It was the latter realization which finally led to the discovery of oxygen, hydrogen, nitrogen, and other gases contained in the atmosphere.

Black's contributions were important both for chemistry and for physics. Like Davy, whom he preceded by half a century, Black worked on border-line problems. Since chemistry as a science is built upon certain fundamental physical principles, it was but natural that those who did most to establish it should have been physicists first and foremost. Black's researches in heat were just as significant as the researches of Rumford and Davy. His clear distinction between intensity of heat, or temperature, and quantity of heat was undoubtedly the greatest forward step in this field since Galileo's invention of the thermometer. But we are here concerned primarily with chemistry, not physics.

Four names stand out prominently in the chemical progress that followed Black's pioneer work on heat and on gases—Cavendish, Priestley, Scheele, and Lavoisier—the

greatest of these being Lavoisier, who was the real founder of the science. These men literally cleared the atmosphere. Boyle did notable work, as has been seen, in ascertaining the relationship of atmospheric pressure to volume, but he little thought that the air contains a number of different gases.

Henry Cavendish (1731-1810) was apparently the first to investigate carefully the heterogeneous character of the air. Before his time there was no clear notion of numerous gases distinct from one another. Several investigators besides Black had detected differences in "airs," but they considered the discrepancies due to some infection or taint in the primordial atmosphere. After a number of important experiments, Cavendish in 1766 published several papers on the subject in which he distinguished a number of gases. Among them was hydrogen, which he called "inflammable air" because of the ease with which it takes fire. Cavendish is justly given credit for the discovery of this important gas. Later he made the remarkable discovery that water is composed of hydrogen and oxygen, though he did not call these gases by their present names. The ancient idea that water is an element was now finally abandoned. In these studies Cavendish came very close to the discovery of those rarer gases of the atmosphere, such as helium, which the research of the last century brought to light. Cavendish also determined the point of temperature at which liquid mercury freezes into a solid form, and he was the first to use mercury for the purpose of collecting gases. He likewise made notable contributions to physics, improving the mercury thermometer, weighing the earth with remarkable accuracy by an ingenious method, and making further advances in the science of electrostatics.

Cavendish was a most eccentric genius. Hating notoriety, shunning his fellow-men, and lacking human sympathy, he

became a virtual recluse, desiring only to be left alone to pursue his researches. He was possessed of great wealth, and at one time was the largest stockholder in the Bank of England, yet he cared nothing for money. With all his eccentricity, he possessed a wide learning and a firm grasp on scientific truth, even though he tenaciously held fast to the phlogiston theory despite its having been discredited fully twenty years before his death in 1810. His masterly analyses stimulated considerable interest in chemical research and influenced Priestley, the preacher-chemist, to enter this field of scientific investigation.

Joseph Priestley (1733-1804) exemplified in his accomplishments what pluck and determination will do against almost insurmountable odds. Unlike Cavendish he was poor, had scant leisure from church duties, and could only at odd moments devote himself to the chemical experiments he loved. But his vigorous mind and perennial optimism converted even obstacles into helps. The very fact that he was forced to devise his own instruments resulted in the perfection at his hands of ingenious forms of chemical apparatus, some of which are used to this day. The most notable of these is the pneumatic trough for collecting gases.

Near Priestley's parish was a brewery where numerous gases were continually being generated. He collected some of these from time to time and determined their properties. Like Black he hit upon carbon dioxide gas, which he thought a kind of impure air. Observing that it is soluble in water, he suggested the use of soda-water as a beverage. He experimented, also, with hydrogen and other gases that Cavendish had discovered; but, like Cavendish, he was unable to shake off the paralyzing grip of the phlogiston theory, which completely masked the meaning of many of the observations he made. His chief claim to scientific

fame rests upon his isolation of oxygen in 1774 and his clear demonstration of its characteristics.

He had been experimenting with red oxide of mercury, a substance occurring freely in nature but not then known to contain mercury and oxygen. By means of a burning-glass (such as boys use to-day to burn the backs of their hands) he had focused the rays of the sun upon the oxide and through the heat produced had freed a quantity of the oxygen, which he collected at his pneumatic trough. To-day we would use an alcohol-lamp or a Bunsen burner to produce the necessary heat, but in those days cruder devices were the only ones available.

The part played in Priestley's isolation of oxygen gas by the burning-glass, a product of physics, is thus indicated in his own words:

> At first I was not possessed of a burning-lens of any considerable force and for want of one I could not possibly make many of the experiments that I had projected. But having afterwards procured a lens of 12 inches diameter and a number of substances, I proceeded with great alacrity to examine by the help of it what kind of air a great variety of substances would yield. On August 1, 1774, I endeavored to extract air from mercurius calcinatus per se [mercuric oxide], and I presently found that, by means of this lens, air was expelled from it very readily. But what surprised me more than I am well able to express was that a candle burned in this air with a remarkably vigorous flame. I was utterly at a loss to account for it.

What Priestley had thus isolated he regarded as similar to common air but better. "Empyrical" and "vital" air were other names later applied to it before Lavoisier demonstrated its true elemental character and called it oxygen. Priestley next proceeded to devise methods for determining the "goodness" of the "air" he had discovered. He compared the length of time a candle burns or a mouse lives

in a certain quantity of the "good air" with what happens in a like quantity of atmospheric air. He breathed some of this new "air" and thus described his sensations: "I fancied that my breast felt peculiarly light and easy for some time afterwards. Who can tell but that in time this pure air may become a fashionable article of luxury? Hitherto only two mice and myself have had the privilege of breathing it."

Fortunately oxygen has not become a luxury for the rich. Its administration in cases of extreme exhaustion or serious illness has saved many lives, and the commercial uses to which it has been put in recent years are many. Oxygen is the most abundant element found in nature in a free gaseous state and under ordinary temperatures. The demonstration of its qualities by Priestley and the final recognition of its elemental character by Lavoisier marked a considerable forward step in chemical progress. In bringing this brief sketch of Priestley's life and work to a close, it is interesting to note that he lies buried in the United States, in the State of Pennsylvania, to which he had come from England during the last years of his life, driven into exile because of his too freely expressed views on the bearing of the French Revolution on political reform in his own country.

The discovery and isolation of oxygen marked an advance in two directions: first, in making it possible to show that it is oxygen and not an imaginary phlogiston which is concerned in the process of combustion; second, in arriving at basic ideas regarding the meaning of chemical elements.

It was left for the great Frenchman, Antoine Laurent Lavoisier (1743-1794), to demonstrate the part oxygen actually plays in calcination or combustion. Black had pointed out that a discrepancy exists between the actual facts and the phlogiston theory. The result of combustion is not a loss but a gain in weight. Priestley and Lavoisier independently discovered that "air" has something to do

with the art of combustion or calcination, one emphasizing the reverse of the process and the other the process itself. Priestley had demonstrated that a calx, which is the product of calcination, when changed back into a metal yields "air" and loses weight. Lavoisier, in several masterly experiments which laid the phlogiston ghost for all time, showed that calcination is accompanied by an absorption of oxygen from the air, and that the resultant calx is heavier because of the weight of the oxygen absorbed. In one of these critical experiments, he heated to the point of calcination a certain quantity of tin in a sealed glass vessel and changed the metallic tin into a gray powdered calx. The sealed glass container weighed the same before and after the experiment, but when the vessel was opened, air rushed into it violently. Lavoisier now weighed the vessel again and found it had become heavier because of the additional air which had entered. The gray calx likewise weighed more than the metallic tin had, and the added weight was identical in both instances. From these results Lavoisier reasoned that some element in the air had united with the tin to form the calx. In another of his experiments he showed that it was oxygen which had thus combined in the reaction. Lavoisier's experiments are of historic value and are well worth detailed examination.

As for the relation of oxygen to basic ideas in chemistry, it is now recognized that the gaseous condition, in which oxygen is freely found, is the simplest of chemical states, and that a knowledge of the properties of any elemental gas goes far in laying a secure foundation for chemical knowledge. All matter is now definitely known to exist in three states, the gaseous, the liquid, and the solid. Many people fail to appreciate even to-day that every chemical element, from the volatile oxygen in the air to the hardest of metals, can be made to exist in all three of these states. By decreas-

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MOLTEN STEEL

ing the temperature and increasing the pressure, oxygen gas can be brought down to a liquid form, and finally to a solid, much as steam is changed into water and then into ice by a lowering of temperature. Liquid air has become a commonplace these days, though the miracles it performs have not yet lost their charm for the onlooker. Conversely, by increasing the temperature, solid gold or any other solid element can be turned into a molten or liquid state and finally vaporized into a gas. Liquid mercury, as it is found under ordinary conditions, can be readily changed into gaseous or solid form. Some substances exist, also, in the colloidal state, which lies between the liquid and the solid, but chemistry is only now beginning to understand the nature of colloids, such as glue or gelatin, so that for our purpose they may be omitted from further consideration here.

All elemental matter, to repeat, can be passed through the gaseous, the liquid, and the solid forms, and the gaseous has been found to be the simplest and easiest to investigate. With the laws of the gaseous state established, it becomes less difficult to work out the laws governing matter in liquid and solid form. From all this it is readily apparent why the discovery of oxygen as an elemental gas was so important for the development of the science of chemistry. And soon after oxygen came to be recognized, hydrogen, nitrogen, and chlorine were ranged alongside of it as elemental gases.

The man who discovered chlorine, a very important bleaching gas and the first to be used in poison-gas warfare in the World War, was Karl Wilhelm Scheele (1742-1786). Scheele was born in Sweden in very poor circumstances, but his remarkable genius for original research knew no barriers, even as Priestley's genius had known none. Apprenticed to an apothecary and denied a college

training, he made the apothecary shop his laboratory. He experimented with tungsten, hydrogen sulphide, and the deadly poison prussic acid, and made brilliant researches on the border-line of chemistry and biology. Yet, like Cavendish and Priestley, he was a stanch phlogistonist. It took the even greater genius of a Lavoisier to deal the final death-blow to this blighting theory. It was Lavoisier, also, who named hydrogen and nitrogen, in addition to oxygen.

It will be remembered that about the time Newton was entering Trinity as an undergraduate, his fellow-countryman Boyle was discrediting the alchemists and suggesting that a new meaning be given the term "element," insisting that it should be applied only to simple, unmingled substances and not to the complex mixtures or compounds, such as earth, air, and water, which were then thought of as elements. A century and a quarter passed before Boyle's suggestion was carried further by Lavoisier. Toward the end of the eighteenth century it had come to be recognized that water is a chemical compound and that the air is a physical mixture. Boyle's distinction had given one clear line of approach to the meaning of elements; namely, that natural bodies cannot be considered as elementary unless no further discernible separation into still simpler forms is possible. Water is not elementary, since it can be broken up into oxygen and hydrogen. Whether or not these gases could theoretically be broken into still simpler forms, Lavoisier did not profess to know. On this point he said, "We cannot be certain that what we think to-day to be simple is indeed simple; all we may say is, that such or such a substance is the actual term whereat chemical analysis has arrived, and that with our present knowledge we are unable to subdivide further." A wise observation this, for to-day science has dissolved matter into sub-elementary forms, but these do not enter into ordinary chemical

analysis and synthesis, for which reason the element remains fundamental in chemical science.

Accepting oxygen and hydrogen as fundamental enough for the purpose Lavoisier now asked: "How distinguish between them? Must we fall back upon their qualities, as that oxygen is 'vital' and hydrogen 'inflammable,' or is there a more exact measuring rod?" Brilliant as Lavoisier's other achievements were, it was his epoch-making reply to these questions which entitles him to be called the founder of the science of chemistry.

His answer was the important generalization, derived from physics, that differences in *weight* differentiate one chemical element from another. For example, if you take equal quantities of oxygen and hydrogen, say, a cubic foot of each, you will find upon weighing them that there is a considerable difference. If you take hydrogen as the unit and select equal volumes, oxygen, in round numbers, weighs 16, nitrogen 14, chlorine 35, mercury 201, and so on through the whole list of elements. These weights came to be known as the atomic weights of the respective elements, after the beginning of the nineteenth century when the atom was defined.

As a second important generalization, Lavoisier asserted that in chemical action "nothing is lost, nothing created—matter is indestructible." He had observed the evidence of this fact in his own experiments, as in his historic experiment on the calcination of tin, and its truth in chemical science has been demonstrated beyond peradventure since. The weight of chemically combined substances is always equal to their weight uncombined.

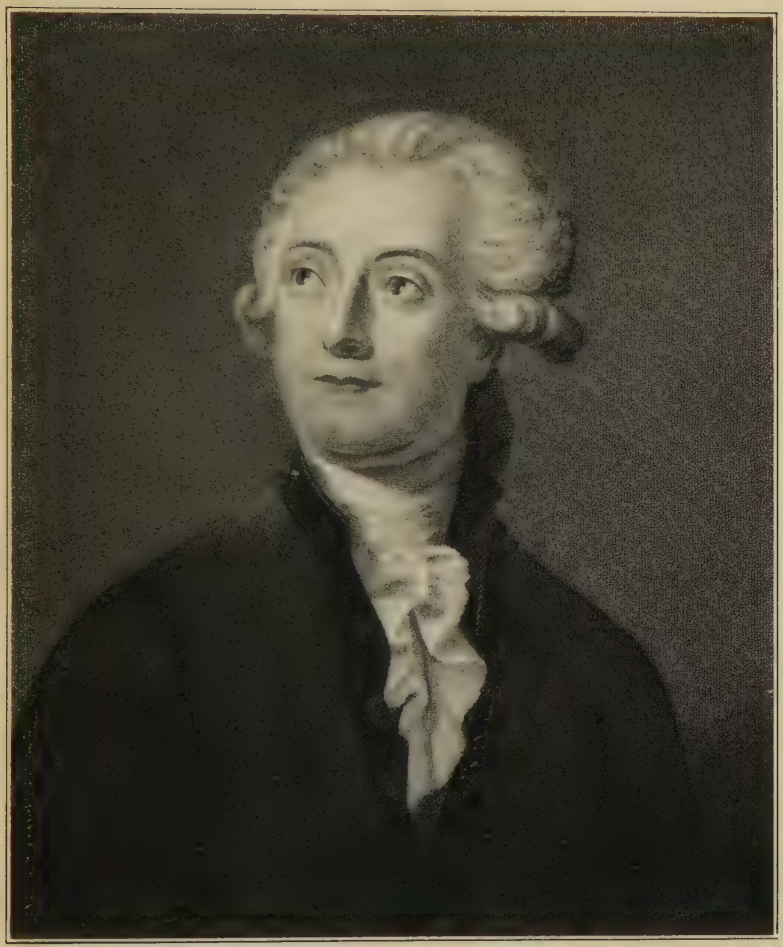
These two generalizations knit the many unrelated observations of Lavoisier's contemporaries and predecessors into an orderly array of facts. The scale or balance became the fundamental tool of chemistry, and quantitative analysis

of chemical changes was made possible. Thirty-three then known substances were declared to be elements by Lavoisier, twenty-three of which are still so recognized. With his discovery of the indestructibility of matter and the basic importance to chemistry of weighing things, the significance of which he outlined in detail in his "Elementary Chemistry," published in 1789, Lavoisier completed the foundations of scientific chemistry.

Nor was Lavoisier solely a chemist despite his brilliant attainments in this field. Born into wealth and the nobility, he had had every advantage. At college he excelled in mathematics and physics and became interested also in geology and biology. It was as a trained physicist and mathematician that Lavoisier approached the study of chemistry, and this accounts in large part for his ability to place his chosen subject upon a secure scientific basis.

Lavoisier was also active in public affairs. He held a number of government posts before the outbreak of the French Revolution, which resulted in his execution as an aristocrat. Upon learning what his fate was to be after one of the monstrous sham trials which followed in the wake of the upheaval, Lavoisier requested that a few days' respite be allowed him to finish some important researches. The reply of the mock tribunal is well known: *La République n'a pas besoin des savants.* What need could there be for research and scientists in a republic?

Grotesque as such a conception may seem to some of us, it is surprising how widespread similar ideas are in our own day. There are many in the so-called proletariat of the world who would make short shrift of all scientists and other leaders of thought on the score that they are unnecessary in a democracy. This is one of the many present-day imponderables in the field of social problems which



LAVOISIER

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must be swept away if man is to guide society into constructive channels.

§ 6

Scientific progress at the end of the eighteenth century in the fields reviewed in this chapter may now be briefly epitomized. In mathematics, the invention of the calculus had opened up new avenues for investigation and for the analysis of natural phenomena. In astronomy, Newton's momentous generalizations had received a thorough test, and an attack on certain special problems had been initiated but could not be followed up until further developments in physics and chemistry were forthcoming. In physics, Newton's inverse-square law had been observed to apply to electrical and magnetic forces, electrostatics had been considerably advanced, and electrodynamics had been founded. In both physics and chemistry, the false theory of imponderables continued to retard progress, although some success had been achieved in discrediting it, especially in chemistry, where the most important inroads had occurred. Here, the imponderable phlogiston had been discarded, the true nature of combustion had finally become manifest, a number of gases had been isolated and analyzed, a precise meaning had been given to the element, and a number of elemental substances had been recognized. Lavoisier had broken the fourth Seal of Science by discovering that matter is indestructible and by making the relative weights of elements the basis upon which the structure of chemical science could be erected.

CHAPTER VIII

OTHER EIGHTEENTH-CENTURY ADVANCES

§ 1

How the seals of mathematics, astronomy, physics, and chemistry were successively loosened and broken, and what progress occurred in these fields from early times to the beginning of the nineteenth century, has now been indicated. In mathematics, the laws of number and of form, both statically and dynamically considered, had been derived, thus bringing about an understanding of human experience in its most general aspects. In astronomy, the laws of motion and of force, in the universe as a whole, had been deduced, and many facts pertaining to the heavenly bodies had been brought to light. In physics, the same laws, in the terrestrial sphere more particularly, had been subjected to further analysis; and in addition such forms of energy as sound, heat, light, electricity, and magnetism had undergone scrutiny. In chemistry, the laws underlying the constitution and composition of matter had begun to be established, without, however, touching upon the manifold concrete forms in which matter appears on earth or its development and variation from age to age. This further, more concrete investigation of matter belongs to the fields of geology and biology, the one examining the inorganic and the other the organic realm. From mathematics through biology, a steady advance in an understanding of human experience has been evidenced, starting with its most abstract and general as-

pects and becoming more and more concrete and intimate with the addition of each new science. And beyond biology lies psychology, which deals with still more intimate phases of our experience, those that we reach primarily through introspection.

The eighteenth century did not pass without some advance in the fields of geology, biology, and psychology; but, since the ground was not made ready for the establishment of these as sciences until microscopic and chemical technique had been perfected, the period could record only further preliminary spade-work in these fields. It must not be overlooked, however, that such preliminary work is necessary to the founding of any science. A considerable amount of fact gathering, even though crude, must precede the orderly formulation of scientific hypotheses.

The ancients had gathered many preliminary facts of importance in the fields of nature study; yet, as has been mentioned, they were without proper tools and made numerous errors. The Middle Ages perpetuated the mistakes of the past with their emphasis on the written word. Sixteenth-century naturalists, with the crumbling of the authority of the ancients, took up anew the gathering of facts, but still without appropriate implements. It was not until the seventeenth century that the microscopists began to see beneath the surface of the superficialities that had previously been adduced.

Even at that, the tools were still inadequate. The simple microscope was not sufficient. The compound and polarizing microscopes and other implements fashioned by physics, and particularly the tools and methods devised by chemistry, were needed to reach still further down until the foundation facts of geology and biology were laid bare. This did not occur till the nineteenth century. Chemistry did not come completely into its own till the close of the eighteenth

century, although even its partial successes, such as the discovery of oxygen in 1774 and the discrediting of the phlogiston theory, had an immediate effect on nature study, especially on biology.

§ 2

The most important guide to any extensive fact gathering is a proper system of classification, or taxonomy, as it is technically called in biology. Classification is necessary in all scientific fields; but in nature study it is of particular importance, for the reason that plants and animals and rocks and other earth forms are exceedingly numerous. There are to-day in the field of biology alone more than a million classified species, each species in itself being a grouping of any number of individual specimens that possess certain points of similarity. There is no such extensive variety in the basic facts upon which the physical sciences are built. The facts of astronomy, physics, and chemistry are few and general compared with the millions upon millions of particular specimens, living or existing only in fossil remains, which nature study comprehends.

Not that fact gathering in the physical sciences is unimportant. When astronomy grouped the heavenly bodies, outside of the sun and moon, into planets and fixed stars, it took a considerable step forward; and this crude classification was merely a beginning, for to-day, in addition, we recognize satellites, comets, meteors, and nebulæ. In physics, a separation of its phenomena into the broad categories of dynamics, sound, heat, light, electricity, and magnetism cleared the way for more penetrating analyses. In chemistry, we have just reviewed the revolutionary effect produced by Lavoisier in making the element the basis of a rational classification there.

In nature study, the multitudinous variety of flora and

fauna and earth formations and deposits led to endless confusion over a long period of time and rendered the problem of taxonomy an extremely difficult one. First attempts in this direction are bound to be superficial and general, and so it was with the nature classifications of the ancients. Living creatures were at first divided into the fish of the sea, the birds of the air, and the beasts of the field; plants into trees, shrubs, and herbs. Aristotle emphasized the value of basing a system of taxonomy upon the structural similarities of organisms, but the tracing of such resemblances was exceedingly superficial until the microscope opened up new vistas of biological and geological facts. No real attempt at a classification of animal, plant, and inorganic forms had apparently been made before the preliminary effort of Aristotle and Theophrastus, and their system held the field with little change until recent times.

Malpighi at Bologna and Ray at Cambridge were the seventeenth-century advance-guards of taxonomic reform. Malpighi's work has already been briefly touched upon. Ray's contribution consisted in giving a more precise meaning to the term "species," which previously had been used too vaguely. A species of plants or animals is a group possessing certain well defined common characteristics. Ray limited the meaning of the term by insisting that the differentiating characteristics show themselves not only in contemporary forms but in their offspring and ancestors. For the first time the important factor of heredity was stressed, though its further significance was not then even vaguely surmised.

The pioneer work of Ray and Malpighi prepared the way for the great Swedish taxonomist, Carolus Linnæus (1707-1778). At an early age, Linnæus had shown a decided interest for nature study, which predilection his father and friends had indulged to the extent of placing him under the

tutelage of a renowned naturalist and of sending him to the University of Upsala. Here he soon attracted attention. At the age of twenty-five, he made a collecting trip of five thousand miles to gather botanical specimens, publishing the findings on his return. Soon afterward he made a second tour, which resulted in 1735 in the appearance of his "Systema Naturæ," a book which immediately became popular and ultimately went through twelve editions.

With the aid of a banker friend who was an enthusiastic amateur botanist, Linnæus was now enabled to devote his time exclusively to biological and geological collections and their classification, writing and publishing six more botanical treatises in the next four years and drawing material from France and England as well as from Sweden. By 1739, at the age of thirty-two, when his reputation was well established, he came back to Sweden from his collecting tours abroad, married, and set up practice as a physician, having secured his medical degree four years before. In 1741 he became associated with the University of Upsala, as professor, first of medicine, and then of botany.

Linnæus was not only an outstanding naturalist. He was also possessed of great charm and power as a lecturer and teacher and drew students to Upsala in considerable numbers. Under his direction many investigators undertook tours of collection in various European countries, sending their findings to the master, who was thus enabled to classify and publish a prodigious amount of additional material. He remained at Upsala for thirty-seven years, until his death. Such had become his fame as the premier naturalist of the day that during his later years, as fast as a paper left his hands for publication, it was translated into the principal languages of Europe.

Linnæus deserves a prominent place as a naturalist, both because of the clear and logical system of classification he

devised, and because of the stimulus his work gave to the further gathering of biological and geological facts. Naturalists found that the Linnæan system could be used with great facility, and this encouraged the collection and classification of specimens to an extent theretofore unheard of. His method consisted in giving to each specimen a brief description suggestive of its special characteristics, and a double name indicative of the species and genus to which it belongs, the genus or more general grouping being indicated first and the species last. This system of double naming, designated as the binomial nomenclature, has been followed to the present day, along with the Linnæan custom of using Latin roots, which resulted in internationalizing the basic terminology of nature study.

The taxonomy of Linnæus was applied in three directions: to botany and zoölogy, which together comprise the field of biology, and to geology. Linnæus was primarily a botanist, and in this field his work of classification was at its best. In zoölogy his system was likewise extremely helpful. In both these fields the Linnæan nomenclature was a great forward step.

In geology, however, the groupings into species and genera proved later to be inapplicable. Here the taxonomic beginnings made by Linnæus were considerably improved upon half a century afterward by Werner, the first geologist to achieve recognition.

Abraham Gottlob Werner (1749-1817) was born in East Prussia and was twenty-nine years old when Linnæus died. Four years before, upon his graduation from the famous Freiberg Mining School with high honors and the completion of a course at the University of Leipsic, he had published a monograph on fossils which secured for him a teaching position at Freiberg. Here he remained for forty years. Like Linnæus, he attracted students in great numbers

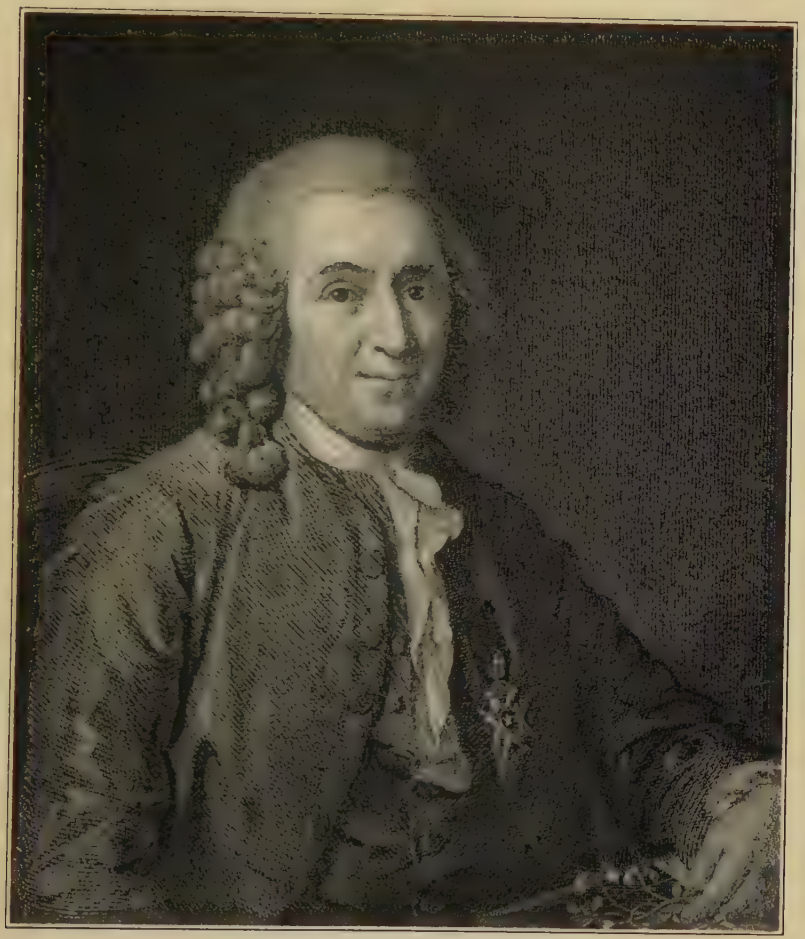
by the force of his personality, his great ability as a teacher, and his careful researches. The School of Mines at Freiberg became a gathering-place for students from all over Europe, and Werner sprang into world prominence as the premier geologist of his day. His writings, however, were of little importance. His strength lay in his teaching ability and in his general knowledge of the geology of his time, shot through with misconception though it was.

Werner improved upon the Linnæan classification of inorganic substances through his painstaking examination of rock forms. His system is based upon mineral composition and structure, and, so far as it goes, is quite in accord with present-day methods. When it came to questions of age and origins, however, he was wide of the mark.

Both Werner and Linnæus were, of course, hampered by an almost total lack of facilities for chemical analysis and by the unperfected state of the eighteenth-century microscope. There was also another handicap under which these men labored, and that had to do with certain misconceptions common in their day. Epoch-making as the Linnæan-Wernerian taxonomy was, the preconceptions of the period rendered it artificial; and this artificiality had to be corrected before either geology or biology could be placed upon a scientific basis.

§ 3

The misconceptions concerned themselves with the origin of the earth and of the animal and plant species existing upon it, and with the manner in which terrestrial changes had occurred in bygone ages. Stories of the creation, of all-embracing floods, and of sudden calamities of one kind and another, as narrated in the Old Testament and elsewhere, had been literally accepted by the vast majority of people, scientists and others; and so long as this literal interpretation continued, nature study remained enmeshed in mis-



LINNÆUS

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understanding. The most far-reaching of these stories had to do with special creations, catastrophic changes, and an essentially cold earth.

The special creation hypothesis had it that there are in existence as many fixed species of animals as originally issued in pairs from the hand of the Creator. This assumption dominated the thought of Linnæus and most of his contemporaries. Species and genera to them meant absolutely fixed and unalterable types, with no merging of one into another such as has since been found to exist. One might ask: what did the Linnæan naturalist do when confronted with a bug which did not fit any of his categories but seemed to lie between two of them? The answer which was credited to one frank zoölogist was that he crushed the unorthodox creature under his foot! This idea of inseparable chasms between species that had originally been molded as distinct and eternally fixed held the field until a relatively recent period and prevented any rational understanding of the origin and development of the earth and of organic life.

Along with the hypothesis of a special creation went the assumption that geological changes come about suddenly rather than in slow stages. This has been called the catastrophic hypothesis. One form of the theory, taken literally from the biblical flood story and tenaciously held by Werner, had it that the whole world was taken to pieces at a certain time, that the pieces were dissolved in an all-embracing ocean which completely enveloped the earth, and that out of this primordial sea various layers of inorganic material were deposited as the waters receded or evaporated. To Werner the interior of the earth was cold, and volcanoes were beds of coal which had caught fire spontaneously and were burning up. These fallacious catastrophic and cold-earth theories he defended most ably; and, despite an even abler opponent who appeared toward the close of

the century, Werner's ideas dominated the geologic thought of his time and well on into the nineteenth century.

The abler opponent of Werner was an older English contemporary, James Hutton, (1726-1797), who was Werner's senior by twenty-three years. Hutton had originally studied law and medicine at the Universities of Edinburgh, Paris, and Leyden, and later took up geology and chemistry. With this broad training as a background, he made extensive observations of geological formations and found they did not accord with Wernerian tenets. He had observed that loose material from all over the earth's surface was being constantly carried into the sea by rainfall and flowing streams. In time, he reasoned, the solid land must thus be carried away. He had also observed that not all rocks are of the same origin. Some contain fossil remains which seem to indicate that they developed as sediments deposited by oceans and streams. Others contain no fossils, are not stratified, and bear signs of having once been in an igneous or molten state. Hutton therefore assumed that the floors of oceans had been raised from time to time by volcanic action and that rocks had been melted in the interior of the earth and had then been thrown forth. He substituted for Werner's cold-earth assumption a hot-earth theory, and for the catastrophic hypothesis one of gradual change and development.

But in this he was arrayed against the outstanding geological authority of the day, and that authority was also sanctioned and upheld by the ecclesiastics, who denounced Hutton as an atheist and a meddler. Hutton's ideas were nevertheless correct, and his treatise published in 1795 and entitled "The Theory of the Earth with Proofs and Illustrations" opens a new era in geological advance.

The time was not ripe, however, for definitely disproving the cold-earth theory. The polarizing microscope and ex-

tensive chemical analysis had to be applied before Hutton's ideas could emerge triumphant, and in the meantime the prolonged controversy between the Huttonians and the Wernerians stimulated further investigation and focused attention on the crucial questions in dispute.

For Hutton did not stand alone. Several of his contemporaries in geology, as well as in biology, did notable work in opposing the conceptions of cataclysmic change and a cold earth, in which connection, so far as geology is concerned, should be mentioned Demarest, the father of physiography, and the elder Saussure, the originator of the term "geology." Their pioneer work is gratefully acknowledged by Hutton in his epoch-making "Theory of the Earth." It was at this time, also, that Laplace's famous nebular hypothesis was put forth, and it accorded fully with Huttonian ideas.

The nebular hypothesis, which has to do with the origin of the earth, is the crowning geological achievement of the eighteenth century. It is, of course, also related to mathematics and astronomy and as such has already received brief mention in the preceding chapter. A more detailed description has been reserved until this time, since the theory not only ties up astronomy with geology but, though somewhat modified, forms even to-day one of the basic assumptions of the science of geology.

The origin of the earth is one of the major problems with which geology deals. It is now a disputed question whether the earth was originally in an incandescent gaseous state, with plant and animal life appearing after its outer surface had become cool enough to sustain organic existence, or whether it was originally a small cold mass, gradually increased in size by the accretion of meteors falling into it, and incapable of sustaining life until it became large enough to attract and hold an atmosphere. The point upon which

most modern authorities are agreed is that the solar system once existed as a nebulous mass (whether hot or cold) and that through purely physical processes, such as condensation, aggregation, and radiation, it has come to its present form.

Such a conception constitutes the central idea of Laplace's nebular hypothesis, and as such it has stood the test of time to the present day. It is in the detailed working out of his scheme that Laplace was very naturally led into error because of the superficial character of geological knowledge in the eighteenth century. Laplace was not alone in putting forth a theory of this character, although it was he who worked out the mathematics of it and in other ways furnished the details which gave his name well deserved prominence in connection with it. The great philosopher Immanuel Kant had suggested a similar theory nearly half a century before, and both Kant and Laplace undoubtedly built upon the ideas of Leibnitz and especially Descartes, who in his theory of vortices started the train of thought which inevitably led to the nebular hypothesis. Before Descartes's theory, there is virtually nothing, even in ancient Greek writings, but fantastic myth and poetic vaporizing to account for the origin of the earth.

Laplace's conception of the original nebula, assuming there was one, is that of an extremely hot gaseous cloud, slowly rotating about a central nucleus which in course of time became the sun. This rotation grew faster, as the nebulous mass contracted and became more solid at its core under its own gravitational pressure, until its speed was such that some of it formed into bands or rings which circled around the more solid inner mass and finally, breaking, collected into globular forms which kept up their movement around the central nucleus and ultimately formed the plan-

ets. In like manner, the planets revolving about their own axes, while still in a very hot and gaseous condition, produced rings out of which the satellites, such as the moon which attends the earth, were formed. The original incandescent earth then cooled and separated into solid, liquid, and gaseous elements, the liquid and gaseous parts forming the atmosphere, streams, and oceans, while the solid portion formed the igneous and sedimentary substances.

Such, in brief, is the celebrated nebular hypothesis, which for a century was regarded as one of the greatest of scientific generalizations, second only to Newton's gravitational hypothesis. Recently advances in geology, physics, and astronomy have cast doubts upon its validity in certain respects. It is now recognized that it is unnecessary to assume a high temperature in the original solar nebula in order to account for the present condition of the sun and its planets. A progressive cooling of the earth is, furthermore, somewhat disproved by present geological evidence. It is also apparent that Laplace's conception of ring formation and nebular motion needs considerable modification.

For a hot nebular hypothesis has recently been substituted a much cooler one, with meteors playing a prominent part in adding to the original masses and heating them internally through collision, pressure, and close packing. The theory of earth origin which is given most credence to-day, though it still has considerable defects, is the so-called planetesimal hypothesis. This holds that the original nebula was a disordered swarm of small masses (planetesimals), moving about a common nucleus with varying orbits, and that through occasional collisions larger bodies were formed until by slow accretion the planets emerged. The original earth is thus thought of as having had from one fourth to one third its present diameter and as growing to

its present size by the addition of planetesimals from the parent nebula, the interior of the earth becoming progressively heated as its size increased. This theory is now receiving careful examination. Whatever its merits, it is obvious that it detracts little from the grandeur of the original hypothesis which was put forth at the close of the eighteenth century, setting before the world the idea of gradual and orderly development as against cataclysmic change—an idea which lies at the very heart of nineteenth and twentieth century progress in geological and biological science.

This is a fitting point at which to leave eighteenth-century geological advance. Aside from the enunciation of the nebular hypothesis, most of it consisted, almost literally, in further preliminary plowing up of the ground. Linnæus and Werner organized a useful but artificial system of classification, holding false theories regarding origins and development, and Hutton's sounder ideas received little support.

§ 4

In turning from geological to further biological progress during this period, it will undoubtedly have been noted that from earliest times the biological aspects of nature study have been stressed, the geological phases neglected. Until recent centuries, in fact, more interest has always been shown in living matter than in inorganic forms. Beginning as a systematic study in ancient Greece, even though proper tools were lacking, and making little progress during the Middle Ages, biology had taken on a modern complexion as early as the sixteenth century, through the efforts of Cordus, Vesalius, and Harvey, and in the succeeding period was already exploring the new world of the microscope, Malpighi pioneering many new paths of inquiry. It had thus secured an advantage over geology and in the eighteenth century was still maintaining its lead; it had at least become

organized into departments, whereas its sister study had not reached that point.

Three important branches of biological research—on both its botanical and its zoölogical sides—had come to be recognized by this time: anatomy, physiology, and embryology. Anatomy treats of the structure of plant and animal organisms. It represents the architecture of the subject, investigating form and layout. It is biological statics. After the break with ancient Greek authority, Vesalius in the sixteenth century, and the microscopists in the seventeenth, laid the groundwork of this important sub-science. Physiology treats of plant and animal functions. It has been aptly spoken of as the mechanical and electrical engineering of the subject. It studies such problems as digestion, respiration, fermentation, circulation. It is biological dynamics, and by its very nature could not develop very far until the chemistry of plant and animal life had become known. The problem of growth or development, as it pertains to particular organisms and not to whole species or races, belongs to embryology, which focuses its attention upon the embryo and traces its development from seed or egg through tissues and organs to the fully formed body. Studies in the development of species and races grew out of advances in anatomy, physiology, and embryology and led ultimately to the much discussed and much misunderstood theory of evolution.

Whereas general anatomy had been delineated in fairly complete outline by the beginning of the eighteenth century, general physiology was not then in any sense understood. Aristotle and Galen among the ancients and Harvey and Malpighi in the seventeenth century had made certain beginnings. But the Newtonian physics was just emerging in Malpighi's day, and chemistry had not yet arisen out of alchemy, so that it was not until the early eighteenth cen-

tury that the mechanics of physiological functions, and not until the nineteenth that their chemistry, could be satisfactorily investigated.

With respect to plant physiology, the seventeenth century had dawned without any inkling that green plants select and digest food much as animals do. The Aristotelian idea that plant food is ready-made in the ground and is then drawn up into the stem, much as a sponge sucks up water, had been but slightly improved upon until Malpighi concluded that the crude elements of plant life are carried through the stem to the leaves, where some kind of action occurs, in which sunlight plays a part, and through which the crude elements are digested, as it were, and sent to the whole plant organism as nutriment.

Here the matter rested until Stephen Hales (1677-1761), a fellow at Cambridge University, established the mechanics of plant nutrition. Through his painstaking experiments, it became clear that plants derive their food not only from the soil but also from the atmosphere, and that the leaves play a much greater part in the process than Malpighi had anticipated. The researches of Hales, brought together in an epoch-making treatise which was published in 1727 under the title of "Vegetable Staticks" (a misnomer, for it had better been named "Vegetable Dynamicks"), were so brilliant and comprehensive that little has since been added regarding the mechanical phases of plant nutrition.

Chemistry had not been born in 1727, nor yet in 1761 when Hales died. After Priestley's discovery of oxygen, he noticed in 1779 that this gas is sometimes liberated by plants; and it was soon afterward demonstrated that, while exposed to sunlight, plants take in carbon dioxide through their leaves, retaining the carbon and discharging the oxygen, and that they also take in oxygen, much as animals do,

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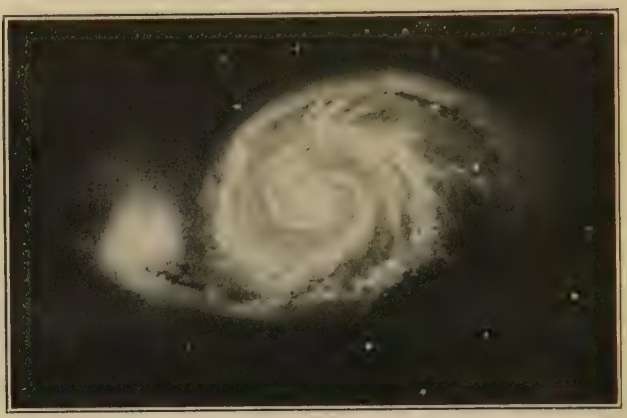

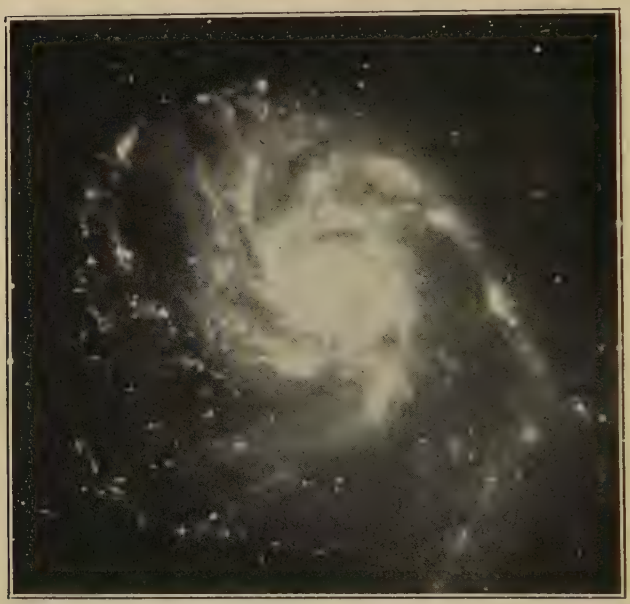

Photos: Mount Wilson Observatory.

GIANT SPIRAL NEBULAE

(In the Great Bear and Hunting Dogs constellations, illustrating the possible origin of the solar system. The nuclei, curved arms, and suggested whirlpool motions are clearly indicated)

and give off carbon dioxide. In sunlight the chief exhalation of plants is oxygen; at night, carbon dioxide.

After the action of oxygen and carbon dioxide in plant life had been discovered, the younger Saussure (1767-1845), son of the eighteenth-century geologist already spoken of, began a notable series of researches and virtually exhausted the chemical phases of plant physiology, as Hales had exhausted the mechanical. This remarkable naturalist was a native of Switzerland and was well educated, but refused several offers of university professorships in order to have more time to carry on his researches in his own way. In addition to verifying conclusively that carbon and oxygen are utilized in plant nutrition and respiration, Saussure showed that hydrogen, nitrogen, and several salts derived from the soil are also used, thus demonstrating in a most dramatic way that organic existence depends intimately upon the inorganic world. Later discoveries simply served to carry Saussure's penetrating analysis a little further along. His book, entitled "Recherches Chimiques sur la Végétation" and published in 1804, placed plant physiology at a point beyond which it has to this day advanced but little.

What Hales and Saussure did for plant physiology, Albrecht von Haller (1708-1777) did in part for animal physiology. Haller was a German biologist, received his training at Bern, Tübingen, and Leyden, and held the chair of anatomy, botany, and medicine at the University of Göttingen for many years. He is said to have been very vain and egotistical, but he was an excellent observer, a scrupulous investigator, and possessed of a vast store of varied information. His enemies caustically referred to him as "that abyss of learning."

After years of successful teaching and research, during which he became an outstanding authority in biology, Haller

published in 1758 one of the most profound and exhaustive treatises ever written, his "Elementa Physiologiæ." In this he brought together all that had previously been discovered in animal physiology, carefully summarizing the work of his predecessors, arranging it in logical form, and adding important material of his own. His book marked a distinct epoch and gave a decided impetus to research into the mechanics and chemistry of animal physiology.

Before Haller's day, this biological field had continued to be studied almost entirely from a medical standpoint. Harvey's discovery of the circulation of the blood, and Malpighi's discovery of capillaries and blood corpuscles, had placed the dynamics of circulation upon a rational basis. But other important bodily functions were still very crudely interpreted. The physicians were, in the main, not interested in the dynamics of the human organism except as this served the immediate needs of their profession. It had required Aristotle to show that both liquids and solids enter the stomach, whereas the physicians of his time were teaching that liquids enter the lungs. Haller definitely separated animal physiology from its medical associations and made it a distinct branch of biology.

Under his influence the physics and chemistry of animal digestion and respiration came to receive serious attention, though it was not until about the time of his death that Priestley discovered oxygen and its importance in physiology began to be understood. With respect to digestion, several of Haller's predecessors and contemporaries should receive credit along with him for establishing the mechanics of the process. Before their time it was not realized that the ingested food undergoes some kind of solution. But the chemistry of the process, involving enzymes and other ferments, was, of course, not known until after chemical knowledge had become further advanced. As for animal respira-

tion, Harvey and others had already overthrown the notions of Galen and his school that breathing is for the purpose of cooling down the heat of the heart. Aristotle had assigned a similar function to the brain, thinking of it as something of a cold-water radiator to keep animals from becoming overheated! With the overthrow of the phlogiston theory, the discovery of oxygen, and an accurate understanding of combustion, came the realization that, in breathing, oxygen is taken from the air to "burn up" the waste materials of the body. Respiration, it is now known, is nothing more than combustion and results in the production of carbon dioxide, which is breathed out.

In the development of plant and animal physiology during this period, Hales, Saussure, Haller, and the chemists played the dominant rôle. By the end of the century it had become manifest that physicochemical laws are the basic elements with which the physiologist has to deal if he would come to an orderly understanding of his subject. So important did chemical research become for this branch of biological study that, with the beginning of the nineteenth century, at least a dozen outstanding investigators turned their energies to experimentation in the combined fields of chemistry and physiology.

In addition to his epoch-making contributions here, Haller followed Malpighi in attempting an analysis of embryological development. In this field two hypotheses were current, the preformation theory and the epigenesis theory; the one advanced by Malpighi and Haller, the other by Aristotle, Harvey, and Kaspar Friedrich Wolff (1733-1794). Both theories in their extreme forms were wrong, and yet both had elements of truth in them.

Harvey had been the first to attempt a critical investigation of the embryo, but had lacked the necessary instruments of minute analysis. He had nevertheless with unaided senses

made careful observations of the chick, deer, and other animals, and, pointing to the ovum or egg as the source of all higher forms of life, had followed Aristotle in believing that the new organism is differentiated out of the previously "unformed material of the egg," in which no sign of the adult parts as such are to be found. This idea, after further elaboration, came to be known as epigenesis.

There had been no preformation theory, so called, in Harvey's day. This had been elaborated half a century later at the hands of the many-sided Malpighi, who in embryology must be ranked above his predecessor Harvey. With the aid of the microscope, Malpighi had worked out various stages of the development of the young chick from the end of the first day of incubation to the moment of hatching. He had made a number of excellent sketches, the best for more than a century to come, showing how the chicken's head, heart, brain, and eyes develop. Through an erroneous observation, however, he thought the rudiments of the future chicken to be preformed in the egg. He had not stressed the idea, but out of it, nevertheless, grew the preformation theory, which set itself squarely against epigenesis.

Between 1672, when Malpighi put forth the suggestion of preformation, and 1759, when Wolff, then a young man of twenty-six, published his "Theoria Generationis," which took sharp issue with it, the theory had been fully developed and was being vigorously defended by the egotistical Haller. By that time several extreme conceptions had been added, the most important to the effect that if the animal exists in the egg preformed, the germs of all past and future generations of man must have existed in the ovary of Eve, "all closely incased one within the other, like the boxes of a Japanese juggler." The alarming conclusion was then advanced that when all these originally incased germs had

been unfolded—and it was figured that two hundred millions of them had already been released—the human race must perforce come to an end!

Wolff, in opposing preformation in the book that has just been mentioned, endeavored with illustrations to prove that "development consists in a gradual formation of parts." But his plates did not bear comparison with those drawn by Malpighi, and his reasoning was inconclusive. He was not able to demonstrate in detail how the various organs of the body develop out of more rudimentary tissues, and he assumed a mystical attitude toward the matter which left him in just as ridiculous a position as the preformationists. "Since he assumed a total lack of organization in the beginning, he was obliged to make development miraculous." He got something out of nothing, and that was just as bad as packing two hundred million germs into one ovary. Yet while his early work did not reach the level of Malpighi's, ten years later Wolff published a paper on the development of the intestine which surpassed the researches of his great predecessor, and which has been designated on high authority (Baer) as "the greatest masterpiece of scientific observation we possess." Recent developments in embryology begin where Wolff left off.

In the eighteenth century, however, his work went for naught. Haller and a contemporary naturalist of note opposed the epigenesis conception with ill concealed scorn. Because of Haller's ungenerous attitude and his great authority, not only was embryological progress retarded for half a century but Wolff was unable to secure a university teaching position in Germany, his native land. In 1764 he went to Russia and became associated with the Academy of Sciences at St. Petersburg. Here he spent the last thirty years of his life.

Wolff was a splendid observer and possessed a sincere

spirit. Writing to Haller, at the height of their controversy, he said: "For me, no more than for you, glorious man, is truth of the very greatest concern. Whether it chance that organic bodies emerge from an invisible into a visible condition, or form themselves out of the air, there is no reason why I should wish the one were truer than the other. . . ."

The conflict between these two embryological theories was of extreme significance for biology. And before further microscopic and chemical analyses had been applied and the conservation of energy theory had been enunciated, it was as logical to hold the one as the other.

Besides advances in physiology and embryology, there was during the eighteenth century one other biological development of the highest importance. This had to do with a foreshadowing of the theory of evolution, which later (at the hands of Charles Darwin) was destined to serve as one of the foundation-stones of the science of life.

Again, as with so many other important matters, the conception of gradual and orderly improvement started with Aristotle, who held in substance the modern theory that the higher forms of organic life have developed in insensible stages out of the lower, and that man represents the highest stage of the evolutionary process. This idea, kept alive in one way or another despite the setback of medieval times, had taken more definite form at the hands of Francis Bacon, Descartes, and Leibnitz, and was further elaborated during the eighteenth century.

Along with Hutton and Laplace, Comte de Buffon (1707-1788), a great French naturalist and writer, and Erasmus Darwin (1731-1802), a highly successful English physician, poet, and naturalist, and grandfather of the world's greatest biologist, took up their cudgels for

orderly development as against special creations, catastrophic change, and all-embracing inundations.

Buffon, like Francis Bacon, appealed to the popular imagination. His great "Histoire Naturelle," in forty-four volumes (partly posthumous), published one book at a time between 1749 and 1804, is ranked as a classic and has had a tremendous influence. Born of noble and wealthy French parentage, Buffon received a thorough education and traveled extensively. His training and social station secured for him the post of keeper of the Royal Museum and the Botanical and Zoölogical Gardens in Paris, where he had abundant opportunity to make observations and prepare the annotations for his series of volumes. His notes were made during the winters and his books written in the summers. Each year the social circles of Paris awaited eagerly the appearance of the next volume, so entertainingly did Buffon write.

Some of the ideas expressed in such a vast and comprehensive piece of work were bound to miss the mark of scientific accuracy, and many did; but there is reason to believe that Buffon deliberately obscured some of his theories in order to escape the ecclesiastical censor. At any rate, unmistakably interwoven through these many volumes is to be found the evolutionary conception. Buffon suggested that environmental influences have much to do with modifications in plant and animal life, that these alterations are transmitted to offspring, and that in the struggle for existence those best adapted to a given environment are the most likely to survive. All these ideas were anticipatory of the modern theory of evolution, and their widespread dissemination through Buffon's interesting volumes did much to point the way for verification in the following century.

While Buffon was at the height of his popularity, Eras-

mus Darwin, born twenty-four years after his brilliant French contemporary, began in England to put the evolutionary hypothesis into unequivocal form. His "Zoonomia," first published in 1794, created a sensation, evoked polemics and apologetics from its many critics, and started a sixty-year controversy, which was not settled till his grandson, the author of "The Origin of Species," set forth the epoch-making results of twenty years of painstaking research. The following excerpts from the "Zoonomia" give a fair example of the clear-cut manner in which the author propounded his views:

> All animals undergo perpetual transformations which are in part produced . . . in consequence of their desires and aversions, of their pleasures and their pains, or of irritations, or of associations; and many of these acquired forms or propensities are transmitted to their posterity. . . . It would appear that all nature exists in a state of perpetual improvement by laws impressed on the atoms of matter by the great Cause of Causes; and that the world may still be in its infancy, and continue to improve forever and ever.

When Erasmus Darwin wrote these words, the time was not in any sense ripe for the evolutionary hypothesis. Years of exacting research were still to pass before the doctrine, stripped of some of its extreme phases, loomed up as an inevitable postulate for geology and biology. In the interim, the pioneer work of Erasmus Darwin, Buffon, Hutton, and Laplace kept the fires of controversy burning until the truth once more separated itself from the dross of misconception.

With the launching of a preliminary theory of evolution (in which the nebular hypothesis and the hot-earth theory were embraced, and to which the special-creation, catastrophic change, and cold-earth conceptions were opposed), eighteenth-century progress in nature study comes

to a close. During this period the binomial system of classification was developed, fact gathering in geology and biology took on a new impetus, and physiology and embryology made significant advances. In addition, important researches were undertaken in the field opened up earlier by Leeuwenhoek and Swammerdam, namely, in that of insect and microscopic life; but these investigations did not immediately affect the main stream of biological progress.

§ 5

With respect to psychology, the last of the fields under review in these chapters on eighteenth-century scientific advance, it will be recalled that, in a previous chapter, both seventeenth and eighteenth century developments were examined. The meagerness and superficiality of available psychological facts, and the confusion of metaphysical with psychological considerations in these two hundred years, were there indicated. The metaphysical assumptions of Descartes, Spinoza, Leibnitz, and Kant, and the critical speculations of Bacon, Hobbes, Locke, Berkeley, and Hume, were set forth. During this entire period there was no apparent appreciation, except possibly in the withering diatribes of Kant at the very end, that the facts underlying the prolonged discussions were wholly inadequate, and that biology must have her say about the sense organs and the nervous system before psychology could begin to build constructively.

Virtually the only real contribution to more adequate psychological facts in these centuries came indirectly through developments in mathematics and physics, especially those having to do with sound and light. These advances gave a new meaning to visual and auditory sense impressions.

Newton had demonstrated that sound is caused by the

vibration of air particles, moving from the object producing them to the ear. If the oscillations are rapid, the tone produced is high and shrill; if slow, the tone is low and deep. He and Huygens had experimented also with light and colors, after which it was later demonstrated that differences in color, as in sound, consist, from the external physical view, only in the rapidity of vibration, or, to express it otherwise, in differences of wave-length. Light, which operates in the ether, will produce a visual sensation of violet if the wave-length of the oscillation be comparatively short. An increase of the wave-length will give different color sensations, varying from blue through green, yellow, and orange, to red.

Before the discoveries of Newton and his co-workers, it had naturally been assumed that tones and colors inhere in external objects, the green in the leaf, musical notes in the throat of the nightingale. But as soon as the significance of the demonstrations of the physicists was made manifest, it came to be appreciated that visual and auditory sensations partake in their creation of internal or psychological factors. Colors and tones, differing only quantitatively in their physical origin as vibrations in the ether or the air, become qualitatively different as they appear in sensation and to the mind. Blue has certainly no measurable relation to red in the mind's eye, and the same is true of musical tones. Visual and auditory sensations, therefore, are altogether different from the physical causes which give rise to them. Here is a profound discovery, both for science and for philosophy—a discovery which does such violence to common-sense impressions that the reader who meets the conception here for the first time will do well to ponder its significance before passing on.

But there are other sensations besides visual and audi-

tory ones. What of touch, taste, and smell? Do these bring us more faithful copies of the objective (external) world, or are they, like sight and hearing, in large part subjective? Here the sciences of physics, chemistry, and biology were still almost completely silent, so that speculative hypotheses were the only alternative, and to these the Bacon-Locke school of English metaphysicians had recourse in their futile endeavors to explain away, now the mental, and now the physical world.

The Englishman Hobbes, recognizing that color as such does not inhere in external objects but that it is produced in the retina and brain of the observer, concluded that sense impressions are therefore wholly illusory and that the objective world possesses the only real existence. Hence his materialism. Hobbes and his fellow-countryman Locke distinguished two kinds of qualities in external bodies: "primary" qualities such as bulk, shape, and motion, which they assumed on inadequate grounds are inherent parts of the bodies; and "secondary" qualities such as colors, sounds, tastes, and smells, which they rightly recognized as sensations produced in us by the objects, but having no point-to-point resemblance to the external forces giving rise to them. Take away the eye, the ear, the palate, and the nose, said Locke, and all colors, sounds, tastes, and odors cease to exist; but, he added, extension, form, and motion will remain. Galileo had preceded the English mental philosophers in drawing this distinction between primary and secondary qualities. Had these men known something of the intricacies of atomic structure which have come to light recently, they would not have been so sure that primary qualities are in a class by themselves. At any rate, Bishop Berkeley blandly obliterated the distinction and placed all qualities on the same plane. This would have been a clari-

fying maneuver, had he not in addition, by a form of specious reasoning, arrived at an absolute negation of matter, just as Hobbes had done with the mind.

Such was the situation during the first half of the eighteenth century—so important for psychology and still so shot through with metaphysical presuppositions that no common ground could be found. The English school objected to the kind of speculation the Franco-German school was using, and yet it indulged in a form of its own. It simply wore its metaphysics with a difference.

It was at this juncture that David Hume (1711-1776), the greatest of the Scotch philosophers, stepped in and attempted to reconcile the Hobbesian and Berkeleyan camps. He pointed out, what is a truism to-day in psychology, that it is useless to try to explain away the external or objective world. It is there regardless of the fact that what we get from it in sensation is different from what it really is. To say that it does not exist unless we are looking at it or experiencing it in some other sensory way is meaningless. The forces that produce our impressions remain, whether the mind comes in direct contact with them or not. On the other hand, Hume continued, there is an inner world of sensation and ideas which we should try by inductive methods to analyze and understand, without troubling about the exact nature of the objective world, which we can never reach anyhow. So Hume proceeded to analyze our subjective experiences in a masterly way, so far as the limited physical and biological facts at his disposal would allow.

He emphasized the oft-noticed phenomenon that ideas tend to bunch themselves together, and that they arise in our thinking in a string or group, a fact recognized in modern psychology in the phrase "association of ideas," as, for example, the idea of "lake" may bring to mind associ-

ated ideas of boating and swimming. Hume worked out the laws of association in considerable detail. His analysis was unquestionably extreme and absolutely mechanistic, but it was doubtless the best that could have been expected in an age dominated by physics and by a superficial conception of psychological facts. Only as biology with its analysis of the nervous system and its genetic point of view came into the ascendancy, was association given a subordinate place and ideas traced back to nerve concomitants and to primitive beginnings in racial history.

Being true followers of Bacon, Hume and his adherents emphasized the thinking phases of psychic life at the expense of feeling and willing; and, finally, from the other side of the channel the Cartesian school once more made reply, this time through the person of Immanuel Kant (1724-1804), the greatest metaphysician of all time. Hume had not only failed to realize that there is more to the inner, psychic life than thinking, but, even in his analysis of observation as a phase of thought processes, he could apparently not discern that the mind has dynamic qualities, that in transforming wave-lengths in the air and ether into sounds and colors it is, as it were, projecting itself into the external world and giving the "noumenon", or *ding an sich,* its own imprint.

Immanuel Kant, the sage of Königsberg, made a solid contribution to the discussion by emphasizing an aspect of the dualism of mind and matter that had been neglected by Hume and the rest of the English school, although like his predecessors, Leibnitz and Descartes, he engaged in metaphysical excursions which befogged certain important issues. It was his penetrating analysis of the inner and outer worlds which caused the words "phenomenon" and "noumenon" to pass into current speech. He held that the psyche has certain inherent powers not given by experience and that these

powers transform chaotic sensations into human understanding. For the negative mental conceptions of the English school, he substituted positive ones; and once more the controversy was on. Nor did it end till each side abandoned its endeavor to belittle the other, and accepted, for psychology if not for metaphysics, the dualism of mind and matter at its face-value without attempting to get behind it.

In setting forth the general situation in psychology at the end of the eighteenth century, we can only repeat what was said in Chapter V. The breakdown of medieval authority after Galileo had opened wide the door to metaphysical speculations closely associated with the subject-matter of psychology—questions regarding the soul, the relative importance of mind and matter, the validity of knowledge, and the like—upon all of which psychology had to learn to turn its back before it could reach workable hypotheses. During the seventeenth, eighteenth, and part of the nineteenth centuries, this clarifying and delimiting process continued.

By the end of the period here under review it had at least become clear that there is such a thing as a psychic or inner life as distinguished from the outer or physical world, and that feeling and willing are equally important with thinking as functions of it. We are to-day all familiar with this threefold division. We say: I am *thinking* of buying a new hat; I *feel* tired or hungry; or I am *determined* to go through the matter. Thought, emotion, and volition have come to be recognized as coördinate major psychological processes, but it must not be thought that they function separately. There is no *pure* thought, feeling, or volition. The psychic life is, in the main, *unitary*. All three elements are always present, though one often predominates temporarily.

The chief obstacle to psychological advance in both the

seventeenth and eighteenth centuries, to repeat what has already received considerable emphasis, consisted in too much speculation with too few facts to go on. Even after biologists had begun to make a serious study of the brain, the spinal cord, the sense organs, and the rest of the nervous system, it was not appreciated for some time that these play a distinctive rôle in psychological activity and must be regarded as furnishing the basic facts of the science. Another deterrent to progress lay in the Cartesian interpretation of introspection, for this prevented investigators from looking in the right direction for their facts. The criticisms of Kant and Hume, together with the current discoveries regarding sound and light, forced a reconsideration of the common-sense meanings previously attached to the terms "observation" and "introspection," the one presumed to apply to scientific procedure in the physical world, the other to the psychic world. It was as a result of this reconsideration that psychological fact-gathering was finally placed on the same plane with the methods pursued in other sciences. How this was brought about will be briefly indicated before we leave the subject.

The seeming conflict between observation and introspection began in ancient Greece, receiving its most pointed expression at the hands of Aristotle and Plato. This was more than two thousand years before discoveries in physics threw new light on the meaning of sense impression. Aristotle had insisted that, despite obvious perceptual shortcomings, the observing of Nature is the only way we have of learning her secrets. On the strength of this assumption the scientific method had arisen. The history of science and the application of scientific discoveries to human welfare amply demonstrate that Aristotle was right. He recognized that the senses are at times deceptive, for which reason he urged repeated observation and experiment, experiment meaning

simply the isolation of phenomena for the purpose of more careful observation. Around these concepts the whole structure of science has been built.

Now, observation is clearly related to sensation, for we can observe only by way of the senses. Seeing, hearing, touching, tasting, or smelling *is* observing. Observations in the realm of physics or biology or in any of the other non-mental sciences, no matter how carefully an investigation is conducted, are accepted at their face-value, uncritically; that is, we pay no attention to the fact that they are sensations and not objective realities. Introspection simply takes an additional step. It proceeds to examine critically into their nature.

Repeated observation is, moreover, not all there is to scientific procedure, as we know it to-day, and as the great men of science have developed it. As has been pointed out, it involves also the setting up of hypotheses and the arrival at generalizations. First we observe nature. We see, hear, touch, taste, and smell the external world. From the sensations experienced we then build up what are called ideas. These ideas may be simple and unrelated, or some of them may be joined together to form a hypothesis, which in turn may serve as a basis for further observations and, if completely borne out, may become a scientific generalization. Sensations, ideas, hypotheses, generalizations—all of these are psychological facts. Both the sciences of the physical world and the science of the mental world utilize them.

Modern psychology takes the many uncritical observational data furnished by the other sciences, and, treating them as sensations, for such they are, subdivides them into visual, auditory, tactile, olfactory, gustatory, and other groups, and proceeds to examine the distinctive qualities of each group—both directly, through the critical and reflective process of introspective observation, and indirectly,

through the ordinary, uncritical observation of their physiological accompaniments. It does the same with thoughts, feelings, and volitions. But a further analysis along these lines must be reserved for a later chapter, when the complete meaning of the psychophysical parallelism has been made manifest; a meaning which assumes that for every psychological activity, conscious or unconscious, there is a corresponding physiological process, either in the sense-organs, the nervous system, or elsewhere.

All we are here interested in is to make clear that to-day the science of psychology utilizes the observational method just as the other sciences do. They all begin with the facts of sensation to build up their scientific structures. Psychology simply advances the process somewhat, adding critical introspective observation to the uncritical type of which it makes use along with the other sciences. Had the mental philosophers of the seventeenth, eighteenth, and nineteenth centuries realized that introspection is nothing more or less than observation carried further, they would undoubtedly have spent less time in metaphysical discussion and more time in looking for the observational facts of psychology.

It was pointed out at the beginning of this chapter that the development of the sciences has been from the most abstract and general phases of phenomenal data (mathematics, astronomy, and physics), through the more concrete aspects as garnered from the inorganic world and from the realm of living organisms (chemistry, geology, and biology), to the still more intimate forms of experience designated as psychological. From generalizations about numbers and form, and motion, force, and energy, we progressed to an analysis of matter, until we were examining the life that expresses itself in plants and animals alike, and in human beings as part of the animal world. We observed animate nature in its objective manifestations as

brought to us through sense impressions. Now, in psychology, we go further and observe it, not only indirectly from without, but also directly from within, and especially as it eventuates in thought, emotion, and volition.

The first critical contact we have with these innermost aspects of life is, of course, through human consciousness. This is both the beginning and the end of psychological study. But most of the thinking-feeling-willing we do is unconscious, is below the threshold, so called. To get a complete picture of the inner, psychic life, it is necessary to analyze subconscious as well as conscious phenomena and to trace back the complex forms now observable in children and in adult human beings to their beginnings in racial and animal history. The ramifications of such problems will be reviewed in the chapter on modern psychology. It cannot be said that at the end of the eighteenth century even a beginning had been made in appreciating them. If this period saw more substantial advances in biology and geology, it must be remembered that none of these three fields had reached its scientific majority at that time.

CHAPTER IX

MODERN PHYSICAL SCIENCE

§ 1

With the nineteenth century began the wonder age of physical knowledge. Discoveries and inventions piled upon discoveries and inventions until the material environment of man was literally transformed. Having broken four of the Seals of Science, man was enabled to penetrate the secrets of the Book of Nature beyond his wildest expectations. His achievements in the last hundred and twenty-five years in harnessing the resources of the universe have been nothing short of herculean.

At the same time, and in marked contrast, nineteenth-century additions to the Book of Society appear as the scribblings of a moron or a maniac. A clearer contrast is hardly conceivable: the highest form of intelligence displayed in the mastery of nature's forces, the crudest kind of stupidity in the ordering of social affairs. What a chapter of medieval muddling of human relations this period reveals! Napoleon, transformed from defender of the republic and wise administrator of domestic affairs to unscrupulous adventurer, arrogantly striding across Europe in tawdry imitation of Alexander, Cæsar, and Charlemagne, while the people of France, duped in their stress and confusion, throw off a democracy so dearly won to return to the very autocracy they have but a few short years before dethroned with horrible violence. The pretentious young czar of Russia entering upon a compact with the ambitious Corsican, on a raft at Tilsit, to subdue and rule the world,

and determining later that the Almighty had given this mission to him alone and that he must destroy Napoleon for its accomplishment. The sweeping aside of the Corsican, only to reveal at the Congress of Vienna a host of still meaner adventurers bent upon reëstablishing the old despotisms. The carving up of Europe, and its division among the kings in utter disregard of the racial, linguistic, and religious interests of the people—a disregard that was to lead to further insurrections and wars. The return to more insolent power of the Bourbons, Hapsburgs, and Hohenzollerns, and their establishment of an unholy alliance to hold the people against a recurrence of democracy. The projected monarchist restoration in South America, prevented only by President Monroe's warning to Europe to keep hands off. The United States itself engaging upon a fratricidal holocaust because some of its inhabitants insisted on owning other inhabitants as personal property—this less than seventy-five years ago. The rise of imperialism and the mad scramble for overseas possessions in which Europeans sought to dominate Africans and Asiatics on the arrogant assumption that the earth can best be governed by the white man, and particularly by a certain group calling themselves Nordics—all in the face of Europe's interminable political wrangling and of Japan's stupendous metamorphosis in a single generation, which should have warned the European that his boasted political and technical ascendancy may be but momentary. And, on top of this, France and England casting themselves in a new rôle as defenders of the Unspeakable Turk to prevent the success of the Russian czar's thrust toward Constantinople. Then, after more maneuverings and insurrections, a "Peace" of Frankfort and a Treaty of Berlin which sowed the seeds of still greater disaster, brought on a mad armament race, resulted in the Entente and the Alliance to maintain an armed truce,

and ended in the greatest slaughter of men and destruction of property the world has ever witnessed.

The hundred years of European diplomacy from 1814 to 1914 are aptly summed up by Wells in his "Outline of History" in the following words:

> We are forced to the conclusion that all the diplomatic fussing, posturing, and scheming, all the intrigue and bloodshed of these years, all the monstrous turmoil and waste of kings and armies, all the wonderful attitudes, deeds, and schemes of the Cavours, Bismarcks, Disraelis, Bonapartes, and the like "great men," might very well have been avoided altogether had Europe but had the sense to instruct a small body of ordinarily honest ethnologists, geographers, and sociologists to draw out its proper boundaries and prescribe suitable forms of government in a reasonable manner.

Nor has the Treaty of Versailles, after the most colossal catastrophe in history, taken these common-sense ethnological, geographical, and sociological factors into rational account. A splendid spectacle indeed! What a period of ignorant and wanton social blundering to set over against concomitant intelligent and orderly achievements in physical science!

The scientific accomplishments of the last century and a a quarter are still astounding the world. They are summed up in what is called the mechanical revolution. This is often confused with certain industrial changes, such as the appearance of the factory system in the eighteenth century; but it is much more than that and came somewhat later, though one of its effects has been to make possible the typical industrial life of to-day through the application of steam to manufacture. It was the mechanical revolution which substituted power-driven machinery for handicraft industry, made possible the rapid transportation of enormous quantities of goods, and provided the means through which the

economic life of mankind could be organized on a world-wide basis. Let us look at some of its other effects.

The steam-engine, a product of physics, came into practical use for pumping and for the operation of cotton mills late in the eighteenth century. In 1804 the first locomotive was constructed; in 1825 the first railway was built; by 1850 Europe was supplied with a number of railroads; and soon afterward the opening up of the western United States became a feasible undertaking. Napoleon's disastrous retreat from Moscow to Paris in 1812, encompassed with all possible haste and convenience for travel, took 312 hours. The coming of the railway reduced the time for the same journey to forty-eight hours and increased the possibility of administering large political units tenfold. For the first time a coherent political life for the vast stretches of the American commonwealth, with continuous access to Washington, was made possible.

In 1807, the *Clermont* steamed up the Hudson, belching black smoke and vivid sparks from its funnel, while the dumfounded New Yorkers lined the shore and gazed in amazement or prayed the Almighty to deliver them from this new emissary of the devil. In 1819 a crude steamship crossed the Atlantic; about 1850 the screw propeller became practicable; and by the end of the century a most uncertain several weeks' adventure on the unknown Atlantic had been transformed into the safest of transits of less than a week's duration and with every conceivable comfort. The uncertainties and dangers of an airship journey to-day are less than those of ocean steamship travel a hundred years ago.

Along with the railway and the steamship came the ocean cable and the electric telegraph to bring the four corners of the world closer together. At the same time man increased his command over structural materials. The steam

hammer, the Bessemer and open-hearth processes for smelting, purifying, casting, and molding iron and steel—all nineteenth-century products—opened up the possibility of building with durable metals on a gigantic scale. Huge engines, ocean liners, suspension-bridges, steel sky-scrapers were soon in widespread use.

Then came the electric light, electric street-cars, electricity used in the household as power—all introduced in the lifetime of people still living. And, finally, after steam power and electric energy, came gasoline power, which meant the development of light engines of greater efficiency, and through which the automobile and the aëroplane have become practicable. Less than four decades old, the automobile has further annihilated space and has in many ways greatly altered the habits of mankind. As for the aëroplane, one would be rash to prophesy. Already regular mail and passenger lines have been established, and the earth has been girt. As this paragraph is being written, two expeditions by air have crossed the frozen north and the pole.

Such are some of the outstanding phases of the mechanical revolution of the last hundred and twenty-five years. That they have given man a wide mastery over his material environment is clear to all. In many respects, also, they have profoundly affected the social structure—not, however, all for the better.

§ 2

With these preliminary remarks regarding the scientific and social developments of the last hundred and twenty-five years, we may turn to an examination of the advances in mathematics, physics, chemistry, and astronomy which lie behind the practical results embodied in the mechanical revolution. A volume could readily be written on modern physical science, so that in attempting to picture it in two

brief chapters—this one and the next—the outstanding aspects only can be touched upon. This drastic foreshortening of our view may detract from the interest of these chapters for the reader. In them, however, and especially in Chapter X, is contained a summary of the most amazing disclosures regarding the material universe that have yet come to light.

There have been several broad epochs, of mathematical advance: first, the Greek period, in which the foundations were laid; second, the medieval Arabian period, which gave us our system of numbers and saw substantial improvements in algebraic technique; third, the period of the sixteenth and seventeenth centuries, which witnessed the rise of coordinate geometry and the calculus, the simplification of mathematical symbolism, the invention of logarithms as an aid to computation, and a further development of trigonometry and algebra; fourth, the period of the eighteenth century, in which the calculus and its derivatives were extensively applied to practical problems in astronomy and physics; and, finally, the fifth or latest period beginning with the nineteenth century. Eighteenth-century progress had been centered in the work of a relatively few outstanding mathematicians, such as Maclaurin, Euler, Lagrange, and Laplace. The last century and a quarter saw the work of these men carried further by a whole host of distinguished mathematicians (so numerous that it is impossible for us to discuss them individually), witnessed the shift of the center of mathematical activity from France to Germany, and beheld the opening up of many new fields of mathematical inquiry. This most recent period has been responsible for mathematical progress in three major directions: first, in a further development of geometry and algebra; second, in a critical examination of the foundations

of pure mathematics; and, third, in important advances in applied mathematics.

With respect to the first of these, it is to be observed, to begin with, that projective, differential, and non-Euclidean geometry have come into existence. Projective geometry applies to such subjects as map making, which casts areas upon a plane from the spherical face of the earth, and is familiar to every one in the geographical maps that are now available. Differential geometry came as an outgrowth of the calculus and consists in an investigation of the properties of plotted figures, such as curvature, through a study of infinitesimal portions of the graphs. Non-Euclidean geometry grew out of futile efforts to derive Euclid's axiom of parallels from his other axioms. This led to the construction of systems of geometry having no necessary relation to a plane, and finally to the establishment of a general system (by Riemann) of which all others, including the Euclidean, were shown to be special cases.

Non-Euclidean geometry, first developed by the noted Russian mathematician Lobachevski, has raised so many profound questions, mathematical and otherwise, that more than cursory mention is warranted here. Without entering into the technical difficulties raised by Euclid's axiom of parallels, a few words of explanation regarding our common-sense impressions of vertical and horizontal lines may be of assistance to an understanding of this interesting subject.

So long as the earth was regarded as flat, vertical and horizontal lines had an unequivocal significance. All vertical directions could be said to be parallel, all horizontal ones straight. But view the earth as a sphere, and difficulties arise. The meaning of "vertical" is then better understood in terms of a plumb-line pointing toward the earth's center,

at which all such lines meet. Hence vertical directions cannot be parallel. A horizontal line is looked upon as perpendicular to the vertical, or, better, as meeting the test that the air-bubble of a carpenter's spirit-level remains centered as the latter is moved along the line. Yet such a test, implying that the air-bubble is always directly over the center of gravity, would make a horizontal direction not a straight line at all but part of the circumference of a great circle of the earth. Following this reasoning a little further, look at the walls of your room. The vertical sides look parallel, the horizontal ones straight; but are they? If the builder has done his work accurately, this question must be answered in the negative. Architectural technique may be Euclidean on paper, and it is, but in practice it is non-Euclidean. Euclidean geometry is plane geometry, but everyday experience on the earth is obviously not composed of life on a plane.

The practical man may immediately respond: "Why all this quibbling? To all intents and purposes vertical lines are parallel and horizontal ones straight." Yet for the exact purposes of science the importance of the question is evident. Furthermore, let the question once be raised, and even more confusing difficulties come along with it. So far as terrestrial experiences go, a spherical geometry added to Euclid's planes would serve man's needs fairly well. But how about outer space? Is it Euclidean, spherical, or what not? Does light actually travel in straight lines, or does man merely imagine that it does, just as he imagines a horizontal direction to be straight? Does space naturally resolve itself into planes and squares and cubes, or is it "warped," as Einstein would have us believe?

Most of us, at one time or another, have stood before a series of concave-convex mirrors at a circus side-show and have watched ourselves change into grotesque shapes, now

fat and squat, now tall and wavy. Possibly our sense impressions are like those images. It may be that we perceive reality in a distorted fashion, or it may be that reality itself is as variable as is our image in an irregular mirror, and that we are in error when we try to make it conform to the regular patterns of Euclidean geometry. At any rate, the constitution of space has of late come to be examined more critically than the ancient Greeks examined it.

Speaking of the importance of non-Euclidean geometry to modern mathematics, a well known writer on science (Clifford) has this to say:

> What Vesalius was to Galen, what Copernicus was to Ptolemy, that was Lobachevski to Euclid. There is, indeed, a somewhat instructive parallel between the last two cases. Copernicus and Lobachevski were both of Slavic origin. Each of them has brought about a revolution in scientific ideas so great that it can only be compared with that wrought by the other. And the reason for the transcendent importance of these two changes is that they are changes in the conception of the cosmos.

So much for the developments of the last century and a quarter in geometrical analysis. They have been revolutionary indeed. Hardly more so, however, than those in algebra. Here the most significant advances have been in a study of variables, such as x and y represented in an equation, and especially of complex variables involving the so-called imaginary. It was during the nineteenth century that the celebrated German mathematician Gauss invented the imaginary as a useful symbol to give meaning to a very disconcerting kind of "number" which was being constantly encountered in algebraic analysis.

To illustrate the nature of this disconcerting concept, take a simple algebraic equation such as $x^2 - a = 0$. Solving, $x^2 = a$, and $x = \sqrt{a}$. Testing out this equation to see if it

satisfies all known values for a, it is seen at a glance that when a positive number is substituted no difficulty is encountered, but if a negative value such as -1 be given, x becomes equal to $\sqrt{-1}$, which corresponds to no conceivable real number. Gauss took the important step of accepting the $\sqrt{-1}$ as a useful mathematical symbol and of giving it a name.

The introduction of the imaginary meant an important advance toward a fuller utilization of algebraic technique, but it was not accepted by mathematicians without protest. It was in the more complete analysis of the meaning to be attached to this troublesome symbol that other mathematical fields opened up with unexpected results, especially in connection with the use of the so-called vector, which is nothing more or less than a magnitude (such as three inches) plus a direction (such as due east). When we say that a fifty-mile gale is blowing from the north, we are using the language of vectors. The employment of these new mathematical concepts signified two things for science: one, that any algebraic formula, no matter what its nature, could henceforth receive a rational interpretation, which meant that the fundamental concepts of algebra were completely established; and the other, that practical problems in physics having to do with such vectors as force and velocity could be more readily solved. In the analysis of a purely abstract mathematical symbol (the imaginary) we have been, as Whitehead expresses it, "led back to the most fundamental of all the laws of nature, laws which have to be in the mind of every engineer as he designs an engine, and of every naval architect as he calculates the stability of a ship. It is no paradox to say that in our most theoretical moods we may be nearest to our most practical applications."

These advances in geometric and algebraic thinking re-

sulted in a critical appraisal of the foundations of the whole science of pure mathematics—the second major development of the modern period. A reëxamination of the relation of geometry to physics led to the realization that space is not necessarily Euclidean. Continuing objections regarding the use of the imaginary focused attention on the question of how far mathematical reasoning applies to reality in the world about us. It came to be recognized finally that mathematics rests on axioms or postulates, self-consistent in themselves so far as logic is concerned, but with no necessary relation to natural phenomena. The last half-century has witnessed considerable progress in clarifying the meaning of mathematical postulates and in indicating their limitations with respect to man's reasoning power and their application to time, space, and energy.

So-called existence theorems have been developed, by means of which it is possible, in advance of attempting a solution, to prove that a given problem can or cannot be solved. By this process several celebrated mathematical puzzles of the past, such as squaring the circle or trisecting an angle by unmarked ruler and compass alone, have been shown to be impossible of resolution. There are, however, some ancient problems apparently capable of solution which are still unraveled, such as the discovery of a formula for picking out the prime numbers; that is, those divisible by no other number but unity. Another consequence of the critical examination of the foundations of mathematics has been the formulation of methods for substituting, in a given mathematical system, one group of symbols for another group without disturbing the relative values within the system as a whole, a very interesting field of study of which no more than brief mention can be made here.

With respect to the third major development of the last century and a quarter, namely, the one pertaining to applied

mathematics, there are several outstanding phases that warrant elucidation here; more detailed examples will be given later on. One phase has been the increasing use of differential equations, a derivative of the calculus, to represent an endless variety of physical problems, even though definite rules have been hard to formulate and, in fact, have been forthcoming with only the simplest form (the linear). The difficulties involved are exceedingly puzzling. Another phase has been the further application of mathematical laws to a study of motion, which has come to be recognized as the fundamental phenomenon of physics. Theories of sound, elasticity, and molecular mechanics have been successfully worked out; but such problems as the rotation of liquids, the movements of the tides, and the motions of the atmosphere have as yet defied explanation. A third phase has been the mathematical formulation of fundamental laws governing natural phenomena, such as the law of the conservation of energy, which will be explained presently; the principle of least action, which involves the working out of a combination of formulæ that will always adopt a minimum value when a system of bodies moves under natural law; and the development of statistical mechanics, which comprehends studies in the properties of a group of moving particles, where the motion of the separate particles cannot be observed, but where certain activities of the whole group are known. Deductions in statistical mechanics are made on the basis of averages and have been successfully applied to the action of gases, to thermodynamics, and to the motions of the stars.

A fourth phase of recent developments in applied mathematics has been the investigation of the continuous medium hypothesis, which holds that no physical action can take place except through the intervention of an uninterrupted medium such as the ether. A famous experiment (the

Michelson-Morley) to ascertain the effect of the earth's motion upon the movement of light through the ether, and extensive observations of particles moving under great speeds, led to startling results and a reconstruction of ideas. These experiments seemed to indicate that length and weight vary with high velocity. The scientific world was dumfounded, nor did it regain its composure with the enunciation of Einstein's theory of relativity, so strikingly borne out in subsequent tests. On top of these startling disclosures came Planck's quantum hypothesis, which runs counter to the generally accepted notion of continuity in nature. According to Planck, "energy is not infinitely divisible but is always received or emitted in exact multiples (quanta) of a fundamental unit." He suggests that space and time are likewise subject to the same kind of fits and starts of discontinuity. The theory is still in a very hazy stage and as yet has no calculus of finite differences to work with. Here, once more, mathematics must perfect an additional tool before further constructive progress can be made. The quantum theory appears to be of importance, and, with relativity, both of which will be touched upon again, should hold out to the student of mathematics and physics a fascinating opportunity for pushing forward the domains of knowledge.

With this forecast we bring our survey of modern mathematics to a close. Many important matters have of necessity been only touched. But if these few pages have given the reader some insight into the tremendous sweep of mathematical technique they have served their purpose. On the whole, mathematics deals with the universe as composed of many heterogeneous things, reduced to points in space and to forms constructed out of points, their number, their idealized form, position, and motion being its central themes. In this analysis of things, it has built up an

elaborate structure of symbols and formulæ for use in an orderly understanding of the most general aspects of natural phenomena, its results being divorced from secondary considerations, which are left to the sciences built upon it.

Mathematics in the twentieth century holds the same basic relationship to the rest of the sciences that it has always held, for it continues to furnish man with the fundamental tools of scientific procedure, and the remaining sciences resort to it increasingly for help. Gauss conceived of it as "the queen of the sciences." Lord Kelvin, one of the greatest of modern physicists, maintained "that when you can measure what you are speaking about and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the stage of a science." The truth of this observation has been amply demonstrated. The same thought is thus expressed by E. W. Hobson, a well known writer on science:

> Probably no other department of knowledge plays a larger part outside its own narrower domain than mathematics. Some of its more elementary conceptions and methods have become part of the common heritage of our civilization, interwoven in the every-day life of the people. Perhaps the greatest labor-saving invention that the world has seen belongs to the formal side of mathematics; I allude to our system of numerical notation. . . . Without taking too literally the celebrated dictum of the great philosopher Kant that the amount of real science to be found in any special subject is the amount of mathematics contained therein, it must be admitted that each branch of science which is concerned with natural phenomena, when it has reached a certain stage of development, becomes accessible to, and has need of, mathematical methods and language.

The great men of physical science have with but few exceptions been mathematicians of the first order, for he who sets out to master science must first master mathematics. Beyond the elements of algebra and geometry, to which we have all been exposed whether willingly or no, the seeker after scientific truth should make himself familiar with coördinate geometry and the calculus and should have at least a speaking acquaintance with differential equations and higher analysis. College mathematics should be so organized that this entire field may be covered in two courses at most, with a minimum of detailed technique and with continual emphasis on the fundamentals. For those who have passed through mathematics in disappointment, but who, nevertheless, are still desirous of understanding its inner meaning beyond the mere smattering that an essay of the present character can provide, it is suggested that Whitehead's excellent "Introduction to Mathematics" be consulted, together with his bibliographical note at the end of the book.

§ 3

The distempered waif called physics, which Galileo found lying on the door-step of science at the beginning of the seventeenth century, has since been fully adopted into the scientific family and in the last century has grown to be a most robust and important member. Galileo, in his day, purged the homeless infant of its worst disorders and left it to the careful nurture of Newton, who saw large promise in the growing youngster and laid the foundations of a useful career for it. The imponderable distemper continued until relatively recent times, but after a final cleansing, the young science entered upon its proper inheritance. It now has taken its rightful place at the table, a place previously occupied by astronomy, and there is no member of the

family which outdoes it in usefulness and in contributing to the welfare of the whole group.

If mathematics may be regarded as queen of the sciences, with a place at the head of the table, physics may now be considered as her ablest daughter. It is modern physics which, with Amazonian prowess, has led in the recent conquest of the material universe and in the harnessing of its energy for the manifold uses of man. The present-day power-driven, electrified, comfort-inured world in which we live would be non-existent but for these accomplishments.

Mathematics has been applied in many practical directions to everyday affairs, and without its guidance physics could never have arisen as a science. Yet in its quest for absolute generality in all things, in its emphasis upon abstraction and symbolism, mathematics was forced to brush aside many matters of day-to-day importance in the experiences of men. Its study of motion is not of concrete bodies—of speeding automobiles or falling apples or the whirl of the stars—but of abstract, idealized points moving in preconceived ways. Its study of matter is not of weight and volume and inertia but of ideal form abstracted from concrete reality. Beyond the most general and conventionalized phases of human experience it is not the purpose of mathematics to venture.

Physics takes the next step. It studies motion and matter too, but in a more concrete way. Starting where mathematics stops, it analyzes the motion of real bodies and such characteristics of matter as weight and volume and the properties of the three most general states—the gaseous, liquid, and solid. In addition, it studies certain manifestations of matter known to-day by the name of energy—such manifestations as sound, heat, light, electricity, and magnetism. This does not mean that physics concerns itself with every phase of matter and energy not dealt with by mathe-

matics, for chemistry and the other members of the scientific family have their own areas of concrete experience to deal with, each starting where the preceding member leaves off.

Physics, in brief, deals with concrete motion, with the general properties of gases, liquids, and solids, and with the various manifestations of energy just mentioned. Has it ever occurred to us how large a part these phenomena are of common day-to-day experience? I look from my window and see gusts of snow whirling hither and thither in the winds, the white-mantled trees sway to and fro, pedestrians make their way along the streets, a branch breaks and falls to the ground, an automobile hurries past. Nor am I sitting here immovable at my desk as it might be supposed. For the earth turns unceasingly on its axis carrying everything on the surface around with it, while at the same time it winds its path about the sun and with that golden orb is taking still another giddy course through space. Nothing is at rest; there is motion everywhere; and the study of the science which fathoms the causes of motion is a useful discipline indeed.

I take stock of my surroundings again. Automobile horns are sounding, a train rumbles and screeches in the distance, the noon whistles begin to blow, the throbbing notes of a canary mingled with the crashing tones of a piano come to my ear. I miss the heat of the sun, which is obscured, am glad the steam radiator is functioning, and wonder how hot it is in the kitchen where food is cooking. I have plenty of daylight notwithstanding the sun's indisposition, yet I realize that a push of a button would flood my room with electric radiance. My thoughts turn to the scores of electric appliances in even the least pretentious of homes to-day—heaters, irons, toasters, percolators, vacuum-cleaners, telephones, electric bells, radios. There is no need to go further

and carry the stock-taking into the factory and the community at large. On every hand we meet the phenomena of sound, heat, light, and electricity, and at every turn we observe how the science of physics has harnessed these forms of energy and has furnished innumerable creature comforts unheard of but half a century ago.

The relation of physics to other sciences, especially to chemistry and astronomy which are nearest of kin, is often misconceived. Some authorities go so far as to say that there is no logical way of differentiating one science from another, insisting that the fields overlap and are bound to overlap. They point to the widely differing schemes of classification proposed by Aristotle, Bacon, Comte, and Spencer as proof of the impossibility of attempting a precise delimitation. Such a philosophy of despair is based upon a failure to understand that the relationship between the sciences has undergone marked changes from time to time and that the connection that now exists is quite different from that of even a hundred years ago, whereas in Aristotle's day there were hardly any departments of science to be classified. Only in historical perspective can the relations between the sciences be understood; and, so viewed, the connection between physics and its sister sciences is clear enough.

Until recent centuries astronomical thinking was necessarily almost entirely abstract and mathematical, since the facts of physics and chemistry, upon which it to-day depends so largely, had not been disclosed. In ancient times, the heavenly bodies were viewed as mathematical entities, as points moving through space, for which reason astronomy stood between mathematics and physics in the sequence of the sciences. For the past century or more, with the application of physical and chemical discoveries to celestial phenomena, astronomy has been exploring a more concrete

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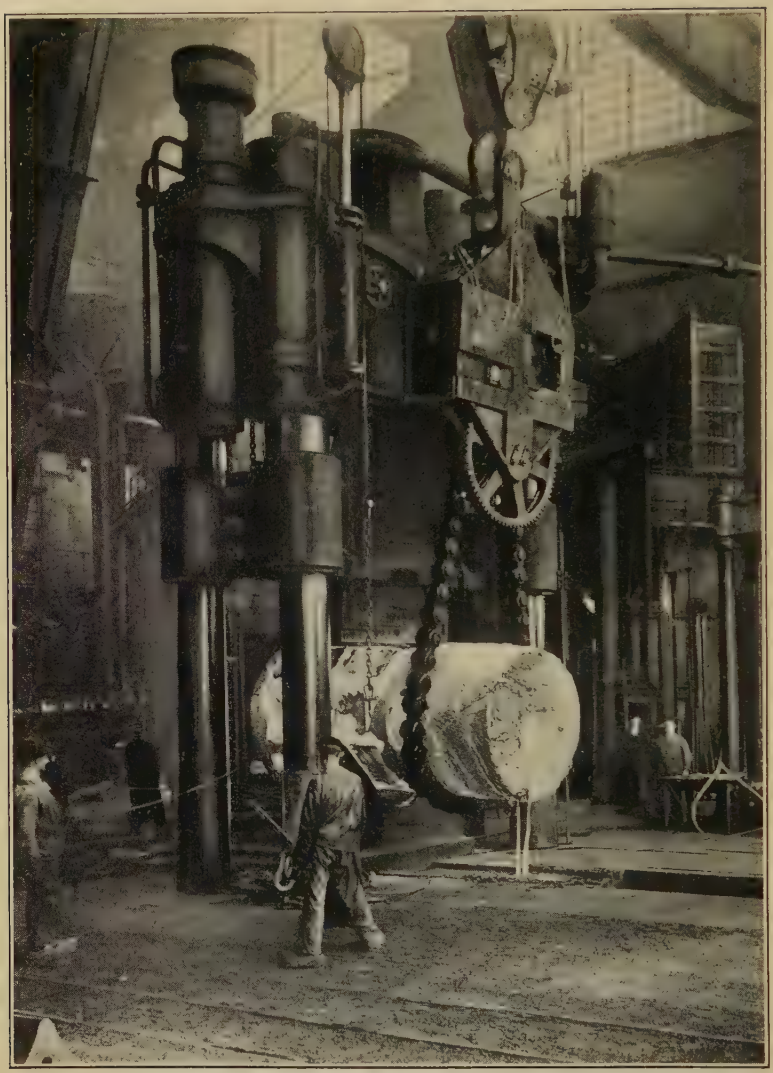

THE ZENITH OF MAN'S COMMAND OVER STRUCTURAL MATERIALS

(forging a white-hot steel ingot, weighing 100 tons, at the Krupp Works in Essen)

universe. Its position in the hierarchy of the sciences has therefore shifted from second to fourth place, following chemistry rather than preceding physics.

The relation of chemistry to physics is likewise readily understood in the light of historical perspective. Before the rise of chemistry as a science, what little was known about the composition of matter had been worked out in the main by physicists, and physics claimed much more as its proper domain than it now possesses. After the beginning of the nineteenth century, the more concrete manifestations of physical phenomena, such as the special characteristics differentiating one elementary substance like mercury or oxygen from another, came to be looked upon as belonging to the domain of chemistry, the more general aspects, such as motion, sound, light, and so on, being reserved for physics. With the still more recent rise of geology and biology as sciences, a further division of labor was necessary between chemists on the one hand and geologists and biologists on the other.

To those who have followed the course of our exposition thus far it should be clear that, inasmuch as all the sciences deal with the same general field of human experience, it is but natural as scientific knowledge widens that new divisions of labor among scientists should result. Viewed historically, each new addition to the scientific family attempted to preempt those portions of experience not fully staked out by older members and only turned over a part of what was regarded as its legitimate domain as younger members of the family appeared and asserted themselves.

In standing between mathematics and chemistry, modern physics is less abstract than the one, less concrete than the other. Whenever it finds it convenient to view a material object as a point in space—and it often finds it thus convenient, as in Newton's analysis of gravitation—it turns

to mathematics for the laws that apply. Whenever its discoveries can give truer meaning to the more concrete researches of chemists, astronomers, and the rest, these other members of the scientific family benefit. Thus all scientific fields are closely connected, albeit a fairly clear-cut division of labor exists among them.

Just as it is necessary to maintain a historical perspective for an understanding of the relation between the sciences, so it is important to hold to the same point of view for a clear comprehension of the various subdivisions now existing in any scientific field. This is especially true in the field of physics. It is simple enough to say that physics deals with matter and energy and with such manifestations as motion, the properties of gases, liquids, and solids, and with sound, heat, light, electricity, and magnetism. But it is somewhat more difficult to show the relationship between matter and energy and their various manifestations, unless historical developments are again kept prominently in view. The connections that Aristotle, Galileo, and Newton saw are quite different from those recognized to-day. There is a marked difference, even, between early nineteenth-century conceptions and twentieth-century ideas along these lines.

§ 4

One hundred years ago the distinction between matter and energy had not yet been drawn, the intimate relationship of motion to other physical phenomena had not yet been established, and the theory of imponderables was still to be completely discarded. To-day the common physical manifestations all about us, such as heat or electricity, have been reduced to modes of motion of particles of matter or of energy moving in the air, the ether, or other media, which play an important part in the results we experience. The fundamental significance of the laws of matter in

motion has come to be more clearly appreciated with each new physical discovery, and the wide acceptance of these laws at the beginning of the nineteenth century cleared the way for further advance. Yet, beyond this, little was known at that time of the relationship of motion to heat, light, electricity, and magnetism. Only sound had been definitely reduced to movement and vibration. Most other physical phenomena were still misconceived.

The formulation of the laws of motion, the joint products of Galileo, Kepler, and Newton, has been aptly described by Whitehead as the first great physical synthesis and as constituting the basis of modern science. How this was accomplished in the consolidation of Galileo's researches on falling bodies, Kepler's discoveries regarding planetary motion, and Newton's hypothesis of universal gravitation, has already been described. Speaking of the significance of these laws, Pearson in his "Grammar of Science" says: "It seems to me that physical science, thus started, resembles the mighty genius of an Arabian tale emerging amid metaphysical exhalations from the bottle in which for long centuries it has been corked down." Whitehead's appraisal, though less picturesque, is just as expressive; he says of Galileo and Newton: "They are to be considered as the parents of modern science and as the joint authors of the first physical synthesis. . . . There would have been no Newton without Galileo; and it is hardly a paradox to say, that there would have been no Galileo without Newton. Galileo was the Julius Cæsar and Newton the Augustus Cæsar of the empire of science."

The laws of motion form the foundations of physical science. But in formulating the gravitational hypothesis which established them, Newton fell into an error regarding the meaning of force, which he construed to be an imponderable what-not residing in matter and as acting from

within bodies through space to draw or pull them together. For the purposes of the sub-science of dynamics, where gravitation is the dominating phenomenon, no great harm can come from investing matter with an anthropomorphic force. But when electrically charged bodies are said to repel or attract one another according to Newton's law, or atoms of matter are thought of as being drawn together by an invested "force of chemical affinity"—and the imponderables have to be manufactured to carry Newton's conception to a logical end—the anthropomorphism results in serious misconception.

To-day the careful physicist does not say that bodies attract or repel. He simply says that they "tractate" or "pellate," to use Frederick Soddy's suggestive words, which is to say that bodies move toward or away from one another, with no implication of the existence of an invested force to explain the movement. In fact, Einstein accounts for gravitation in quite an un-Newtonian manner. He accepts Newton's hypothesis that bodies have a natural tendency to move in straight lines but suggests that the reason they move toward or away from one another may be the condition of "space" in the neighborhood of matter. If space in the vicinity of material bodies becomes warped or twisted, the "space-lanes" would no longer be straight, and the bodies would then tend to move under the influence of the warping!

At the beginning of the nineteenth century the idea of invested essences—the imponderables—was still deeply rooted in scientific thinking. Although this erroneous idea did not hold back progress in dynamics, it did stifle advance along other lines, since the imponderables—effluvia, caloric, phlogiston, and corpuscle—had seemingly nothing in common. Each belonged to a world of its own and thus kept the studies of electricity, magnetism, heat, and light effec-

tively separated. In these fields Newton's conception of force was a stumbling-block and a delusion.

How the various manifestations of energy other than sound were finally related one to another and reduced to modes of motion in an all-pervasive ether forms one of two great epics of nineteenth-century physical advance. This will now be briefly outlined.

In *electricity* and *magnetism* the marked activity of the end of the eighteenth century continued unabated into the nineteenth. The sensational interest created by the invention of the Leyden jar, the development of the principle of conductivity and insulation, the famous kite experiment of Franklin and the acceptance of his one-fluid theory of frictional electricity, the application of the principles of mathematics and dynamics to electrical and magnetic attractions and repulsions, the classical controversy between Volta and Galvani which led to the discovery of current electricity and the invention of the battery—these advances were followed in the early nineteenth century by numerous experiments to determine just what the long-suspected relationship between electricity and magnetism actually is.

Oersted, a Danish physicist, made an accidental discovery in 1820 which led the way. While experimenting with a wire through which an electric current was flowing he happened to hold it over a compass-needle and noticed that the needle was deflected just as if a magnet had been brought near it. This observation was followed up by Ampère (1775-1836), an eminent French mathematician and physicist, and by Faraday (1791-1867), a brilliant English experimentalist in physics and chemistry. Between them these two scientists discovered that electric currents act upon one another precisely as though each is surrounded by a magnetic field, that the hypothetical field turns a piece of iron into a magnet, and that a wire placed in the field has

an electric current produced in it. Thus were created the electromagnet and current electricity by induction, two of the important developments that entered into the mechanical revolution.

In addition, Ampère proved that the attractions and repulsions he had observed in his experiments follow Newton's laws—a most difficult mathematical achievement, which earned for him the right to be known by subsequent generations as the Newton of electricity. Faraday, with a subtle intuitive sense that has rarely been equaled, made further notable discoveries, following up Davy's pioneer experiments on the electric arc and electrolysis, and discerning relationships and principles which he later demonstrated experimentally or which succeeding mathematicians established by rigorous proof.

At the same time, Ohm (1789-1854), a German mathematician and physicist, worked out the connection between what we to-day call volts, amperes, and ohms; in other words, between the strength of a current, the amount of the flow, and the resistance of the circuit. This relationship now constitutes the basis of all quantitative studies in current electricity, and is known the world over as Ohm's law.

At the hands of Oersted, Ampère, Faraday, and Ohm, during the first half of the nineteenth century, the mathematical laws governing the behavior of current electricity were formulated, the relation of electricity to magnetism was completely elucidated, and the fields of electrolysis, electrodynamics, and electromagnetic induction were established. These were the achievements which made possible the later inventions of the dynamo, motor, and electric light. They constituted the second great physical synthesis.

Concurrently, a similar line of advance was taking place with respect to *heat*. Following the heroic though unsuccess-

ful efforts of Rumford and Davy at the close of the eighteenth century to discredit the caloric imponderable, Fourier and Carnot in the first quarter of the nineteenth century and Mayer, Joule, Kelvin, and Helmholtz in the second quarter discovered the laws of thermodynamics and established the principle of the conservation of energy.

During the days of Fourier (1768-1830) and Carnot (1796-1837), perpetual motion without corresponding exertion seemed a perfectly feasible outcome of the recently invented steam-engine, since nothing to the contrary had been proved. It was Carnot who established the principle which blasted this hope and which has been picturesquely expressed in Slosson's "Creative Chemistry" as follows:

> There is one law that regulates all animate and inanimate things. It is formulated in various ways, for instance: Running down hill is easy. . . . Herbert Spencer calls it the dissolution of definite coherent heterogeneity into indefinite incoherent homogeneity. Mother Goose expresses it in the fable of Humpty Dumpty, and the business man extracts the moral as, "You can't unscramble an egg." The theologian calls it the dogma of natural depravity. The physicist calls it the second law of thermodynamics. . . .

As Carnot stated the principle, it simply meant that heat tends to flow from a higher to a lower temperature. It was sometime later, through the establishment of the theory of the conservation of energy, that its full significance was grasped and the idea of producing energy without expending a corresponding amount of effort was abandoned by informed people.

The men most responsible for this achievement were Mayer (1814-1878) and Joule (1818-1889), one a German physician and the other an English brewer and amateur physicist. Standing out against the prejudices of the world of physics which was still devotedly fondling the caloric

theory, these two outsiders collected their evidence, met the inevitable rebuffs, and finally laid conclusive evidence before their unbelieving contemporaries that the energy "lost" in heat dissipation is always reappearing in an equivalent amount in some other form, such as motion or mechanical work. Fortunately two young men inside the fold of the professional scientists—young men who were later to be elevated to the nobility in Germany and England for their services to science, as Count von Helmholtz and Lord Kelvin—saw the significance of this generalization. With Helmholtz (1821-1894) and Kelvin (1824-1907), who among other accomplishments were mathematicians of the first rank, the theory of the conservation of energy was put upon a sound mathematical basis. By 1860, through the combined labors of these four men, the obsequies of caloric, which Rumford had hoped to witness some sixty years before, had finally been read, heat energy had at last come to be recognized as due to the friction of molecules of matter, and the indestructibility of energy had been accepted as axiomatic. These men completed the third great physical synthesis.

With respect to the fields of *light* and *optics,* there had been little progress after the historic controversy between Newton and Huygens at the close of the seventeenth century, until Young and Fresnel more than one hundred years later revived the undulatory hypothesis and perfected it. Young (1773-1829), a distinguished English physicist, was several years under thirty when at the opening of the eighteenth century he took his bold stand in favor of Huygens's discredited theory, the more audacious in that he was opposing an elaborated corpuscular hypothesis fathered by the great Laplace, then at the height of his fame. Young's contentions found little support, although they included the suggestion of transverse waves to solve the difficulties of

CLERK-MAXWELL

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polarization, until there began appearing in 1816 the searching mathematical and experimental memoirs of the young Frenchman Fresnel (1788-1827), which conclusively settled every point in dispute and completely dethroned the corpuscular imponderable. The immediate effect of Fresnel's work was to focus attention upon the question of the existence and properties of the ether, which had to be assumed as part of the undulatory theory, and to draw a host of noted mathematical physicists into this intriguing field of investigation. Then came Faraday's researches, the enunciation of the law of energy conservation, and a concerted effort on the part of a number of able physicists to reduce all manifestations of energy, other than sound, to modes of vibration in the ether.

Faraday, with his remarkable intuitive insight, had become convinced that there are no fundamental barriers such as the imponderables had erected between heat, light, electricity, and so on, and as a result had made (in 1845) one of his most notable discoveries; namely, that a magnetic field will act to change the plane of polarization of light. In this experiment, Faraday demonstrated that electricity, magnetism, and light are in some way intimately associated. Two years later young Helmholtz was taking up his cudgels for the conservation-of-energy theory and boldly asserting that heat, light, electricity, magnetism, and chemical action are all reducible to modes of motion.

Clerk-Maxwell (1831-1879), a brilliant Scotch mathematician and physicist, put the capping stone upon these endeavors. By strict mathematical reasoning he proved that the media which carry light on the one hand and electricity and magnetism on the other are one and the same and that these three manifestations of energy must be ultimately identical. Maxwell was one of the ablest of modern scientists. Profoundly impressed with Faraday's unusual genius,

he had decided to avoid all mathematical treatises on the properties of the ether and electricity until he had mastered Faraday's unmathematical work. After accomplishing his purpose, he applied his superb knowledge of mathematics and converted into exact terminology many of Faraday's intuitive observations. This finally led to the enunciation of his now world-famous electromagnetic theory of light in 1873, which completed the fourth great physical synthesis.

Thirteen years later Hertz verified experimentally Maxwell's conclusions regarding the velocity and properties of electromagnetic waves, discovered the waves that bear his name, and laid the foundations for the wonders of the wireless.

This, then, closes our brief review of one of the nineteenth-century epics of physical advance. Three of four great physical syntheses sum it up, the first one having been formulated before the century began. Electricity, magnetism, heat, and light came to be recognized toward the end of the period as manifestations of the motion of material particles transferred to undulations in an all-pervasive medium called the ether. The questions now very naturally thundering for an answer from many quarters had to do with the character of material particles; that is, with the structure of the atom and with the more precise determination of the nature of the ether. How these questions were answered constitutes the other epic in modern physical advance, happily described as the Romance of the Nineties, but before this can be intelligently unfolded, it will be well to have before us the pertinent facts that the chemists had in the meantime been bringing to the fore.

CHAPTER X

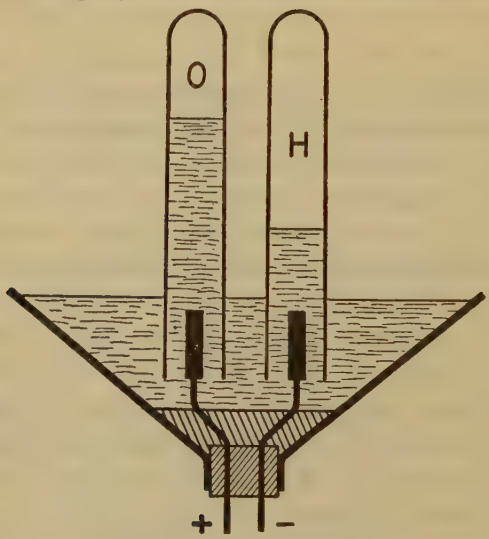
CHEMICAL, ATOMIC, AND COSMIC ENERGY

§ 1

At the beginning of the nineteenth century, chemistry was about as Lavoisier had left it, just emerging as a science. Some of the commoner elements, such as oxygen, nitrogen, and hydrogen, had been isolated; the true character of combustion had been ascertained; the phlogiston theory had been discredited; the principle that matter is indestructible had been established; the fact that elements may be differentiated one from another on the basis of weight had been made clear; and a number of the then known substances had been designated as elements. In 1800 twenty-seven were known; by 1830 the number had doubled; and since that time another thirty-five or so have been added, making at present ninety elements in all.

The discovery and isolation of elements constituted a most important preliminary step in building up the scientific structure of chemistry. In the nineteenth century this was considerably aided by two significant advances in physics. One was the application to chemical analysis of the newly discovered principles of current electricity by Sir Humphry Davy in 1806. Pursuing an accidental observation by others that the terminal wires of a battery when dipped in water cause bubbles of gas to arise, Davy demonstrated in a series of interesting experiments that pure oxygen can be produced at one wire and pure hydrogen at the other. Inferring that the passage of an electric current decomposes a

compound into its elements, he now tried the experiment with liquid potash and succeeded in producing beautiful silver globules which took fire on reaching the air. Thus was potassium, as Davy named the new element, isolated for the first time, and a new method of chemical analysis launched, the method of electrolysis. To-day the electrolytic technique is employed in extensive commercial activities



ELECTROLYSIS OF WATER

having to do with electroplating, the refining of metals, electrotyping, and additional technological processes.

The other physical advance which aided in the investigation of elements was the development of the spectroscope by Bunsen and Kirchhoff about 1860. The principal part of this effective instrument is a prism of glass, through which light is refracted to obtain a spectrum much after the method Newton employed to break up sunlight into its components. Every chemical element, whether dissociated or in a compound, is now known to produce, when heated

to incandescence and viewed through the spectroscope, a series of bright lines or colors, whose positions are unique and unvarying for each element. The instrument is so sensitive that with it the presence of the minutest fraction of an element can be detected and is so devised that comparisons of spectra can readily be made. Through its use a number of elements previously unknown were discovered.

The application of spectrum analysis to light from the sun and stars has afforded an opportunity for comparing the chemical elements present on bodies in remote regions of stellar space with those located on our own planet. With very few exceptions the elements on the sun, the stars, and the earth have been found to be identical. Every one has to-day heard of helium gas because of its use in airships. This element has an interesting history, for it was first discovered in 1868 in the sun, in the form of an unfamiliar spectrum line that could not be attributed to any known substance. It was not until thirty years later that its presence was detected on the earth.

§ 2

Many other interesting incidents could be told of the search for the more than sixty elements brought to light in the last century and a quarter, but limited space forbids our pursuing the topic further. The discovery and isolation of the elements, important as that is for chemical advance, is after all a mere preliminary step. A much more difficult task is the precise determination of their comparative weights and of their combining power in forming compounds.

It is to-day confidently held that the elements are composed of minute particles called atoms which in the gaseous state move about with great freedom. It is also held that, under similar conditions of pressure and temperature, equal

volumes of different elemental gases contain the same number of atoms. There are exceptions to this rule, but we may omit them for the moment. Comparative elemental weights have come to be looked upon as comparative atomic weights, and it would seem offhand a simple procedure to take equal volumes of elemental gases under proper conditions and weigh them, thus solving the problem of their respective weights. This, in fact, was done by Lavoisier and his followers for hydrogen, nitrogen, oxygen, and other gases, the approximate comparative weights relative to hydrogen having already been indicated.

There are certain difficulties, however, in this procedure. First, it is not easy to make sure that the gas with which you are experimenting is absolutely pure, that it does not contain admixtures of other gases. Secondly, only a very few elements are transformed into gases at feasible temperatures. Molten zinc (788° Fahrenheit) is difficult enough to experiment with, whereas the temperature required to produce gaseous zinc is much higher (1706° F.). Other elements require an even higher temperature before they change into gases, so that comparison on the basis of gas volume is of very limited applicability. Nor is there any simple way of comparing volumes of gases with volumes of liquids or masses of solids. Obscure changes in bulk occur when elements are transformed from the gaseous to other forms.

In an effort to circumvent the obstacles encountered in computing the atomic weights of elements not conveniently handled in the gaseous state, an indirect method of analysis came to be employed which developed out of the pioneer work of Davy on electrolysis and the later discovery by Faraday (in 1833) of the laws of electrolytic dissociation. This indirect process led to the determination of so-called equivalent combining weights, which bear definite ratios

to atomic weights but are not identical with them. The determination of these ratios presented another difficulty, especially since it was soon found that the same element often has more than one combining weight and that elements do not necessarily combine atom for atom. They have differing "affinities" for one another. The formula for water is not HO but H_2O, meaning that here two atoms of hydrogen mate with one of oxygen. In hydrochloric acid, HCl, containing hydrogen and chlorine, only one atom of hydrogen enters into a molecule of the compound. In methane or fire-damp, CH_4, containing hydrogen and carbon, four atoms of hydrogen enter. Using hydrogen as a basis for comparison, one would say that in the foregoing instances chlorine has the same affinity or drawing power as hydrogen, that oxygen has twice as much, and that carbon has four times as much. In modern chemistry this drawing power of an element in combining with other elements is called its valence. The valence or valences of every element had to be ascertained before the relation of equivalent combining weights to atomic weights could be established.

In this enumeration of the difficulties which make the problem of ascertaining atomic weights a hard one, certain hypotheses and definitions that assist the present-day chemist have been taken for granted. The task of the early nineteenth-century investigator was, however, much more troublesome; for atoms, molecules, and valences were then unknown, and even the now well established fact that compounds are formed by an invariable ratio of weight between elements was in dispute.

Soon after Lavoisier's enunciation of the law of the conservation of matter, that the weights of substances are never changed whether elements are combined or free, two French chemists (Proust and Berthollet) took sides on the question of whether compounds have an invariable com-

position or not. The outcome of the controversy was the establishment of the so-called law that elements combine in *definite proportions by weight.* Proust showed conclusively that Berthollet's discrepancies were due to the use of mixtures of substances rather than pure compounds, an important distinction. A mixture is physical, such as sand mixed with sugar, with constituents which can exist in any proportion. A compound is chemical, such as water, H_2O, with constituents which always appear in one definite ratio by weight. Proust also observed that some elements, as in the illustration with respect to hydrogen in a preceding paragraph, combine in more than one proportion by weight, but he did not observe that these varying proportions bear a simple multiple relation to one another, as 1, 2, 3, 4. The eminent chemist Dalton (1766-1844) discovered this important principle in 1804 and called it the *law of multiple proportions,* the forerunner of the conception of valence.

About 1804 also, Dalton developed his famous atomic theory, in which Lavoisier's law of the conservation of matter, Proust's law of definite proportions, and his own law of multiple proportions are all comprehended. The atomic theory was elaborated in Dalton's "New System of Chemical Philosophy," which appeared in 1808.

That matter is composed of small particles or atoms was a suggestion that had been put forth here and there since early Greek times, but it was not until Dalton demonstrated how such a hypothesis reconciled and explained discordant observations that it was taken seriously. His theory holds that chemical elements consist of atoms which differ in weight for the different elements, but are for the same element all precisely alike and uniform in weight and other characteristics. These atoms, Dalton continued, combine chemically in simple proportions; that is, one or more atoms of one element combine with one or more atoms of another

element to form a so-called molecule of the compound. A molecule of water (H_2O) contains three atoms, two of hydrogen and one of oxygen; and in any compound the molecule is to be regarded as representing its smallest unit, just as the atom is to be considered the smallest unit in the element. Subsequent research has only served to justify Dalton's assumptions, except that, with the discovery of so-called *isotopes*, atoms even of the same element can no longer be regarded as being all precisely alike.

The establishment of the atomic theory was of the utmost importance for chemical advance. It not only aided in an understanding of elemental weights in terms of atomic weights, as has already been indicated, but it also presented a clear picture of the structure of compound substances and of the procedure to be followed in building them up, once their formulæ were known. Yet the determination of the formulæ remained a task of considerable difficulty, for in order to ascertain in each instance the particular affinities or valences of the elements involved it was necessary to comprehend the changes in volume which usually accompany chemical reactions. It was in this connection that in 1811 the Italian chemist Avogadro (1776-1856) launched another hypothesis which, had its importance been appreciated at the time, would have saved much tedious labor for early nineteenth-century chemists. What Lavoisier, Proust, and Dalton did with *weight* in chemical analysis, Avogadro attempted to do with *volume*.

It was tacitly assumed with the enunciation of the atomic theory that under comparable conditions there are always the same number of atoms in equal volumes of gases, and this assumption does hold true for most of the common elemental gases as already suggested. But with other gases the assumption soon led to confusion, for there is often a shrinkage in volume when a compound gas is formed, as,

for example, two cubic inches of hydrogen added to one cubic inch of oxygen do not produce three cubic inches of water vapor (steam), as might be supposed, but only *two*. It is impossible, therefore, for a cubic inch of a shrunken compound gas to have the same number of unchangeable atoms as a cubic inch of one of its constituent elemental gases. It was this discrepancy which Avogadro's hypothesis sought to explain. Avogadro maintained, in brief, that equal volumes of gases, whether elementary or compound, contain under comparable conditions the same number of molecules (rather than atoms), and that elements as well as compounds must have a molecular constitution to explain the observed facts. In other words, a molecule, whether it contains two, three, or more atoms, always occupies the same amount of space, the phenomenon of volume shrinkage being accounted for on the score that more atoms are crowded into a molecule of the contracted compound than were packed into the molecules of the elements taking part in the reaction. In Avogadro's day, however, several of the concepts we have just been discussing were not clearly understood, with the result that no attention was paid to his hypothesis for nearly half a century.

It would be beyond the plan of this book to enter further into the problems confronting the early nineteenth-century chemist. Suffice it to say that with the beginning of the century men like Dalton, Davy, and Avogadro, and later Faraday, Bunsen, Kirchhoff, and others, enunciated the theories and devised the tools and methods which made possible a most rapid development of the new science after the first half of the century had passed. Making clear the meaning of atoms, molecules, and valences, and the effect of weight, volume, spectra, and electrolysis upon the analysis and synthesis of chemical substances, was the necessary prelude to the later advance.

§ 3

Startling progress in chemistry began around 1860, the year Avogadro's hypothesis was resurrected from the oblivion into which it had fallen, to explain much that had been mystery before. The effect was felt first in the field of organic chemistry.

So-called organic compounds, such as make up the fibers and tissues, and the saps, fluids, and secretions of plants and animals, were for a long time thought to be produced wholly by some kind of "vital" force and thus to be unamenable to chemical analysis and synthesis. In 1823 this notion was dispelled by the great German chemist Wöhler (1800-1882), who produced the animal secretion urea from the inorganic substances nitrogen and hydrogen. Further research demonstrated, in fact, that the chief constituents of organic compounds are four elements—carbon, hydrogen, oxygen, and nitrogen—which are combined in multitudinous ways to make up the living matter found in the plant and animal kingdoms.

With Wöhler in this early period of organic chemistry must be associated the name of Liebig (1803-1873), who "instituted systematic laboratory instruction in Germany." He founded what was for a time the most famous chemical school in the world. Out of it came many of the leaders in the advances that followed. Liebig himself did exceedingly important pioneer work on the border-line between chemistry and biology.

Systematic organic chemistry may be said to have taken its rise with Wöhler and Liebig. Yet progress in their day was slow. Molecular constitution was then still misunderstood, and valences were as yet unheard of. With a clear explanation of these important matters by 1860, came also the utilization of polarized light for analyzing organic com-

pounds, of "radicles" for explaining certain unusual chemical reactions, and, finally, of chemical formulæ for presenting a graphic picture of organic constitution. As early as 1823 it had been noticed that the plane of polarized light in passing through certain organic substances is rotated. Pasteur and others later examined this optical effect further and ascertained its value as an analytical tool for studying such substances as the several varieties of sugars. Radicles are unstable groupings of atoms, such as SO_4, which act as units in compounds but are seldom isolated as such. A chemical formula, as has already been suggested, is a grouping of symbols representing the elements and compounds taking part in a reaction and indicating the number of atoms and molecules involved. These equations are simplicity itself, provided it be remembered that the juxtaposition of two or more symbols without intervening arithmetical signs, as H_2O, means molecular constitution, that the subscript numeral at the right of a symbol indicates the number of atoms involved (if more than one), and that a number placed before the symbols, as $2H_2O$, signifies the quantity of molecules as a whole that are being considered. Thus the formula $2H_2+O_2=2H_2O$ means that two molecules of hydrogen (H_2) added to one of oxygen (O_2)—each of them, it will be noted, containing two atoms to the molecule—will under suitable conditions produce two molecules of water vapor (H_2O), or steam, as it is commonly known.

The use of such graphic formulæ paved the way for a systematic nomenclature and revolutionized progress in organic chemistry during the last four decades of the nineteenth century. One hundred and fifty thousand compounds have now been successfully analyzed and their equations indicated. Vast numbers of new compounds have been synthetically produced; and many of these are not reproduc-

tions of what is found in nature but substances entirely new in the history of the world. So far as natural compounds are concerned, once their chemical structure is established, they can be built up out of their elements. As for the new syntheses, a fascinating series of stories indeed, as of aniline dyes, might be told if space permitted. Slosson narrates them superbly in his "Creative Chemistry." Germany's sudden rise to industrial eminence toward the end of the nineteenth century is interwoven with developments of this sort. Huge industries have arisen in a number of countries to give commercial value to the marvelous advances in synthetic chemistry; and dyes, drugs, antiseptics, anesthetics, perfumes, and flavors that were non-existent but a few decades ago are now in wide and increasing use. The new impetus in organic chemistry has by no means spent itself. There are many signs, in fact, that this field is still in its infancy.

As for inorganic or general chemistry, rapid advance has come only recently. After general chemistry laid the groundwork upon which the organic branch built, it remained comparatively undeveloped up to the close of the last century, both because further tools were difficult to devise and additional principles hard to formulate, and because organic chemistry with its fascinating appeal absorbed most of the workers. Organic chemistry, despite its charm and importance, deals in the main with but four elements (carbon, hydrogen, oxygen, and nitrogen) and with reactions that take place within a very circumscribed field of temperatures and pressures, for living organisms can survive under ordinary atmospheric conditions only. In the inorganic field, on the other hand, one deals with all the elements (ninety of which are now known), and, in addition to ordinary compounds, with substances dropped as meteors from the skies or thrown as igneous masses from the bowels of the earth, formed under temperatures and pressures to which

living organisms could never be subjected, and which must in some way be reproduced if the composition of such inorganic substances is to be fully understood. Electric furnaces to secure thousands of degrees of heat, devices for penetrating hundreds of degrees below our zero temperatures, pressures of almost inconceivable intensity, vacuums of near perfection—such were the additional physical tools for which inorganic chemistry had to wait, and which have only recently been provided.

The principles of this branch of chemical science are based upon the physical laws of gravitation, thermodynamics, electrodynamics, optics, electrolysis, and others which were themselves not enunciated much before the middle of the century, and some of which were not established till much later. In fact, it is precisely the purpose of inorganic or general chemistry to determine what effect weight, volume, pressure, heat, light, electricity, and other physical forces have upon the reactions and transformations of chemical substances.

The discovery and isolation of the elements, the precise determination of their comparative weights and of their combining powers in forming compounds, the establishment of the conceptions of atoms, molecules, and valences, and the development of electrolytic and spectroscopic methods of analysis—all these belong to the field of general chemistry, as do also the discovery of "radicles" and optical effects and the development of chemical formulæ. The point here is that the revival of interest after 1860 concentrated itself first upon the very limited field of organic compounds and only widened its scope later.

The application of electrolytic methods to chemical analysis brought with it a number of confusing problems which were not cleared up until 1887, when Arrhenius (1859 —) enunciated his theory of electrolytic dissociation. It

had been observed that a number of substances, which in solution form the best conductors of electricity (electrolytes, we now call them), exhibit changes in molecular weight. Arrhenius suggested that the molecules of substances in solution split up into two or more parts which he called "ions," each acting as an independent molecule and as a carrier of the electric current. The ionization hypothesis has clarified many perplexities and stands as one of the important mile-stones in general chemical advance. A few years earlier Gibbs of Yale (1839-1903) had worked out the principle of chemical equilibrium, marking another mile-stone. This demonstrates why it is that a reaction taking place in one direction—such as carbon monoxide (CO) and steam (H_2O) combining to form carbon dioxide (CO_2) and hydrogen (H_2)—comes to a state of rest and then reverses itself to form the original constituents (in this instance CO and H_2O). Gibbs's principle has also cleared up a number of difficulties, but as it was hard to comprehend it was not generally employed till some years after its enunciation.

With the work of Gibbs and Arrhenius building on that of Mayer, Joule, Faraday, and Maxwell, inorganic chemistry began to take on new life and interest around 1890. Especially notable in this recent advance has been the extensive application of the laws of temperature and pressure to chemical reactions, and of inorganic chemistry as a whole to the practical needs of mankind.

Questions of boiling-points and freezing-points have been exhaustively studied, the most spectacular developments being the liquefaction of what had previously been thought to be "permanent" gases and the determination of a so-called absolute zero, 273° below the centigrade scale. The table given below indicates the temperatures at which, under suitable pressures, several well known "permanent" gases

liquefy and, also, those at which they freeze into a solid form.

LIQUEFACTION AND SOLIDIFICATION OF GASES

Substance	*Date when first liquefied*	*Condenses to liquid form*	*Freezes to solid form*
Oxygen	1883	—118° Cent.	—235° Cent.
Nitrogen	1883	—146° "	—215° "
Hydrogen	1898	—243° "	—248° "
Helium	1908	—268° "	—272° (about)

The practical uses to which inorganic chemistry has been put in the present generation are legion. The manifold applications of nitrogen, in high explosives that deal out death on the field of battle, as well as in the nitrates of fertilizers that help to give life to the plant world; the stupendous development of synthetic poisonous gases such as phosgene, chloropicrin, and mustard gas, of the last of which the Germans are said to have used twenty-five hundred tons in one offensive of ten days; the metamorphoses accomplished by the electric furnace in producing carborundum, sodium, and cheap aluminum, and in combining and separating other substances otherwise impossible of practical utilization; modern methods of rust-proofing iron, of producing high-speed tool alloys, of making electric-light filaments, of putting the rare-earth elements to practical use, especially the radioactive substances like radium—these are some of the high spots of the accomplishment.

And if we are to believe some of the enthusiasts among the chemists, this science on both its organic and inorganic sides is only at the threshold of its service to mankind. In the near future they say chemistry will dwarf the revolutionary achievements of physics. A synthetic age is foreseen in which substitutes will be found for all man's needs when the natural supply falls short. The new atomic-hydrogen flame, which generates eight thousand degrees of heat

(Fahrenheit), is being looked to as the precursor of an epoch-making age of alloys. A day is visioned when volcanoes will be harnessed for the uses of industry. It is even contemplated that a drug is coming which will promptly neutralize fatigue poisons and act as a partial substitute for sleep, and that a further knowledge of the chemistry of glands will enable man to control genius, morals, and sex! Some chemists are not so sanguine; others see frightful wars ahead in which deadlier poisonous gases will destroy whole populations in a few days; but all expect much more from their science in the future than has yet come to pass.

§ 4

In the last quarter of the nineteenth century, after the intimate relationship between heat, electricity, magnetism, and light had been completely established and all these manifestations of energy had been reduced to modes of motion in a circumambient ether, skepticism over the existence of such an all-pervasive medium began to subside, and the question which had already been raised with respect to heat became more insistent with respect to all forms of energy; namely, what is there about matter which occasions these manifestations, these modes of motion in the ether? The answer to this question lies obviously in the constitution of matter or, more precisely, in the structure of the atom. All lanes had led to the same door, and after Maxwell's day an increasing number of physicists came to hammer upon it with ever louder insistence, demanding that it be opened.

Unable at first to penetrate the mystery of atomic structure, physicists had busied themselves with an analysis of atomic behavior (as in gases); and in this connection it became possible, after the establishment of the laws of thermodynamics and of certain important principles in

chemistry, to calculate mathematically just how large atoms and molecules are, what they weigh, how fast they move in various gases and under different pressures, and what paths they take. In the face of the fact that atoms are almost inconceivably small—in a drop of water magnified to the size of the earth, their relative magnitudes would still be no larger than footballs—the achievement of weighing and measuring them and of tracing their paths was no ordinary accomplishment. The revelations here were astonishing enough. But the physicists were by no means satisfied. They insisted on finding out how the atom is built up.

It was as the result of one of Maxwell's suggestions that the right key was fitted to the lock of atomic structure. Maxwell had predicted about 1875 that the next significant advance in an understanding of matter and energy would come from the study of electrical discharges through rarefied gases; and for twenty years devoted disciples had followed the master's intimation without apparent effect. But finally, toward the close of the century, three great discoveries burst upon the scientific horizon, revelations which so aroused the world of scientists that, as Professor Bumstead of Yale expresses it, "the physical journals were awaited with an impatience not unlike the desire for newspapers in war time." These discoveries—of X-rays, radioactivity, and the electron—constituted the Romance of the Nineties which has been spoken of in the preceding chapter as the second great epic of modern physical advance. So startling and unexpected were they, however, that their significance with respect to atomic structure could not be fully grasped for some years.

The first of these discoveries, the X-ray, was made in 1895 by Röntgen (1845-1922), professor of experimental physics at the University of Munich, while experimenting with a glass vacuum-tube through which electricity was

passed by means of conducting wires sealed into the glass. The current as it flows across the vacuum or near-vacuum in such a tube sets up a beautiful glow and, Röntgen observed, produces certain peculiar rays which not only pass through the glass container with great ease but also pass through most other substances with a facility depending upon the density of the substance. Since these rays affect a photographic plate they have proved of inestimable value to the medical practitioner in making shadow photographs of the human body, the fleshy outline being revealed as a very faint shadow, tumors or other abnormal growths as somewhat darker, bones darker still, and bullets or other metallic substances almost black, since they offer the greatest resistance to the passage of the rays. Röntgen called these peculiar emanations X-rays because for some time they remained almost entirely inexplicable in the light of the known laws of physics. It was Sir William Bragg and his son who later demonstrated the identity of X-rays and light waves through their remarkable researches in crystallography.

The year after Röntgen's discovery, Becquerel (1852-1908), professor of physics at the Ecole Polytechnique in Paris, noticed that the ores of uranium, without any apparent stimulation such as a current of electricity affords, emit another kind of peculiar ray which penetrates many bodies and which likewise affects a photographic plate. The whole scientific world was now astir. Two years later, in 1898, interest was further heightened by the Curies' discovery of the element radium in the same ores and their establishment of the fact that it is this element which gives forth the Becquerel emanations. Subsequently additional radioactive elements have been revealed, and the cause of their emanations has been traced to an internal atomic breakdown, in the process of which they are transmuted into other ele-

ments, as, for example, radium is gradually converted into lead. Part of the dream of the alchemists has come true, though we have found no way of hastening or retarding or otherwise controlling the transformations.

These discoveries of new forms of energy were followed soon afterward by the identification by J. J. Thomson (1856—), professor of physics at the University of Cambridge, of a particle of matter smaller than the atom. This soon came to be known as the electron and has since been shown to be the ultimate ingredient of negative electricity as well as a constituent of all matter. It has now been established that X-rays, radium emissions, and emanations from incandescent bodies, such as find their practical application to-day in the audion and thermionic tubes of the wireless and the radio, are nothing more or less than streams of tiny "disembodied" electrons, as small with respect to the atom as atoms are small in a drop of water.

The discovery of the electron and a nucleus in the atom called the proton has enabled us finally, after some years of further investigation and discussion, to see into the fairyland of atomic structure. The result has been new conceptions of matter and energy so startling as to be well nigh unbelievable. They do such violence to preconceived notions that man comes away stunned and blinded from his first gaze. All advance in science, as has been evidenced time and again in preceding pages, means a discarding of superficial common-sense impressions. It requires some stretch of the imagination to appreciate that the sun does not actually traverse the heavens from east to west as it appears to do. But this adjustment of man to his universe is mere child's play compared with the adjustments that are now required.

Our senses tell us that a table-top is even and compact. Twentieth-century physics insists that we are mistaken, that we see an object as solid only because our vision is not fine

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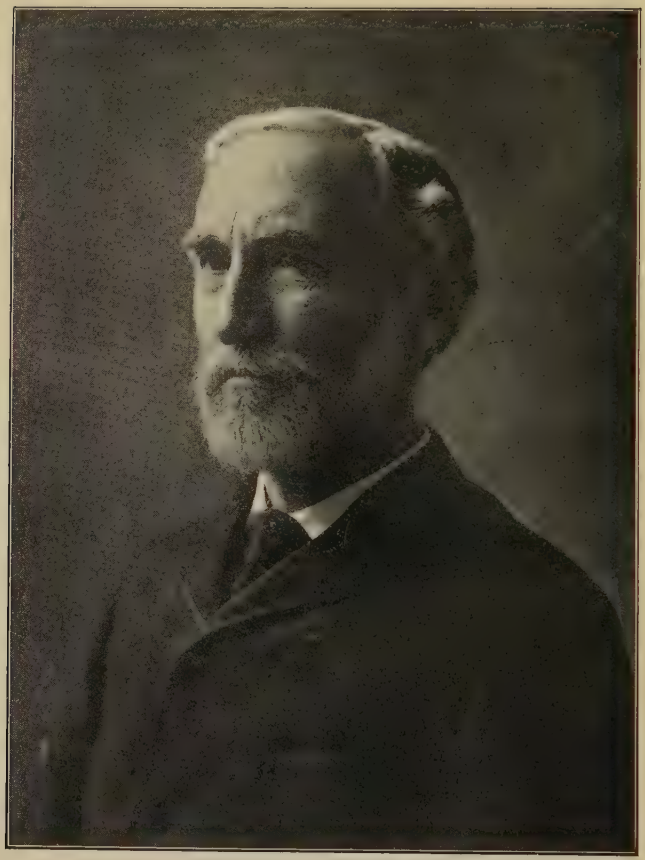

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enough, that as a matter of fact the smoothest-appearing material is in reality an intricate open network with the knots in the netting cut loose, and, as if this were insufficient, that each knot is a miniature solar system with small particles of something or other called electrons (matter or energy or what not), moving with incredible speeds and yet in perfect Keplerian orbits about their central protons, and that the relation of the size of the particles to the gaps between them and their nuclei is comparable to the relation of the size of the planets in the solar system to the spaces that intervene between them and the sun. In this connection, Planck's daring assumption that energy is not sent forth from the atom in continuous streams, but as an ebb and flow of periodic disturbances, appears more intelligible. The revolution of electrons about their central atomic nuclei may give us intermittent rather than continuous energy manifestations. But where is smoothness and compactness, and what, in these latter days, are matter and energy? Here the mystery has become more profound rather than more simple; for in this Alice-in-Wonderland universe which is forced upon our unwilling comprehensions, we are told that electrons and protons, which together make up all there is of the atom, are the ultimate constituents of *both* matter and energy. The electron *is* negative electricity; the proton *is* positive electricity; and taken together they form matter! A fairyland, indeed, nor can we rub our eyes and expect to see the vision disappear when the wireless and the radio are two of a number of concrete embodiments of the new knowledge. The enigma of the relation of matter to energy is still with us.

Besides unlocking the mysteries of atomic structure, the revelations of the nineties provided a better understanding of the nature of elements, thus lending aid to the chemist as well as to the physicist. It is now clear that one element

differs from another chiefly in the number of electrons associated with the protonic nucleus of the atom, and electronic number has come to supersede atomic weight as the distinguishing characteristic of elements. The hydrogen atom has only one electron, the helium atom has two, nitrogen has seven, gold seventy-nine, mercury eighty, lead eighty-two, radium eighty-eight. The radium atom loses six electrons in the transformation into lead. Rutherford recently bombarded nitrogen with helium to obtain hydrogen and in doing so evidently tore loose some of the electrons. If a mercury atom could be induced to lose one, gold would be produced—a transformation already attempted and in some quarters declared to have been consummated.

We have not yet mentioned another important development with respect to elements which preceded the discovery of the electron by some thirty years. This was the enunciation of the so-called periodic law by Mendelyeev (1834-1907), a noted Russian chemist. In arranging chemical elements in a series, on the basis of increasing atomic weight, he found that certain characteristics recur periodically and that the elements fall into well defined groups such as the inert gases or the alkali metals. Noticing several blank spaces in his periodic sequence, he predicted that three new elements would be found and indicated what their properties would be. These were later actually discovered and given the names of scandium, gallium, and germanium after the nationalities of their finders. When electronic number (generally called atomic number) came to be used in place of atomic weight, added meaning was given to Mendelyeev's law. His serial arrangement became even more significant. As the periodic table now stands, ninety-two elements are provided for, only two of which are still unknown.

Turning from the structure of the atom to inquiries into the existence and nature of the ether, which constitute the

PERIODIC TABLE OF THE ELEMENTS

(ATOMIC NUMBERS ARE INDICATED ABOVE THE ELEMENTS, ATOMIC WEIGHTS BELOW)

	GROUP 0	GROUP I	GROUP II	GROUP III	GROUP IV	GROUP V	GROUP VI	GROUP VII	GROUP VIII		
1 HYDROGEN H 1.008	2 HELIUM HE 4.00	3 LITHIUM Li 6.94	4 BERYLLIUM Be 9.0	5 BORON B 10.9	6 CARBON C 12.000	7 NITROGEN N 14.008	8 OXYGEN O 16.000	9 FLUORINE F 19.0			
	10 NEON NE 20.2	11 SODIUM Na 23.00	12 MAGNESIUM Mg 24.32	13 ALUMINIUM AL 27.0	14 SILICON Si 28.1	15 PHOSPHORUS P 31.04	16 SULFUR S 32.06	17 CHLORINE CL 35.46			
	18 ARGON A 39.9	19 POTASSIUM K 39.10	20 CALCIUM CA 40.07	21 SCANDIUM Sc 45.1	22 TITANIUM Ti 48.1	23 VANADIUM V 51.0	24 CHROMIUM Cr 52.0	25 MANGANESE Mn 54.93	26 IRON Fe 55.84	27 COBALT Co 58.97	28 NICKEL Ni 58.68
		29 COPPER Cu 63.57	30 ZINC Zn 65.37	31 GALLIUM GA 70.0	32 GERMANIUM Ge 72.5	33 ARSENIC As 74.96	34 SELENIUM Se 79.2	35 BROMINE Br 79.92			
	36 KRYPTON Kr 82.92	37 RUBIDIUM Rb 85.45	38 STRONTIUM Sr 87.63	39 YTTRIUM Y 89.0	40 ZIRCONIUM Zr 90.6	41 COLUMBIUM Cb 93.1	42 MOLYBDENUM Mo 96.0	43 MASURIUM MA ?	44 RUTHENIUM Ru 101.7	45 RHODIUM Rh 102.9	46 PALLADIUM Pd 106.7
		47 SILVER Ag 107.88	48 CADMIUM Cd 112.40	49 INDIUM In 114.8	50 TIN Sn 118.7	51 ANTIMONY Sb 122.0	52 TELLURIUM Te 127.5	53 IODINE I 126.92			
	54 XENON Xe 130.2	55 CAESIUM Cs 132.81	56 BARIUM Ba 137.37	57 LANTHANUM LA 139.0	58 CERIUM Ce 140.25	59 PRASEODYMIUM Pr 140.9	60 NEODYMIUM Nd 144.3	61 ILLINIUM Il ?			
		62 SAMARIUM Sm 150.4	63 EUROPIUM Eu 152.0	64 GADOLINIUM Gd 157.3	65 TERBIUM Tb 159.2	66 DYSPROSIUM Dy 162.5	67 HOLMIUM Ho 163.5	68 ERBIUM Er 167.7			
		69 THULIUM Tm 169.4	70 YTTERBIUM Yb 173.5	71 LUTECIUM Lu 175.0	72 HAFNIUM Hf 178.6	73 TANTALUM Ta 181.5	74 TUNGSTEN W 184.0	75 RHENIUM Re ?	76 OSMIUM Os 190.9	77 IRIDIUM Ir 193.1	78 PLATINUM Pt 195.2
		79 GOLD Au 197.2	80 MERCURY Hg 200.6	81 THALLIUM Tl 204.4	82 LEAD Pb 207.20	83 BISMUTH Bi 209.0	84 POLONIUM Po (210)	85 ———			
	86 RADON Rd 222.0	87 ———	88 RADIUM Ra 226.0	89 ACTINIUM Ac ?	90 THORIUM Th 232.18	91 BREVIUM Bv ?	92 URANIUM U 238.2				

NOTE: ELEMENTS FROM 57 THROUGH 71 BELONG TO THE SAME FAMILY, IN GROUP III.

second line of attack upon the citadel of the meaning of energy (for it is in a circumambient ether that all forms of energy other than sound are said to manifest themselves), we find that recent developments are equally startling and bewildering for the physicist.

Until very recently it was assumed that the ether is as a whole at rest and immovable, that light and other energy waves travel on it in every direction with equal freedom, and that the earth in its motion passes through it without causing so much as a ripple. But if these assumptions are true, it should be possible to measure the earth's motion relative to the ether. Take a bird flying the length of a train, for example. If the train is at rest, the bird will cover the distance in a certain time; if the train is moving in the direction of the bird's journey, the time of its flight will be longer; if in the opposite direction, shorter. Now substitute a beam of light for the bird and a given distance on the earth's surface for the train. When the earth is traveling in the direction of the light's journey, the time taken by the light to traverse the given distance should be longer than when the earth is moving in the opposite direction; and the difference should be readily calculable, since the resultant of the three motions of the earth—its axial, orbital, and stellar velocities—is well known.

The most famous attempt to test experimentally the earth's movement or drift through the ether was made in 1887 by Michelson and Morley, two noted American physicists, by means of the so-called interferometer, an invention of Professor Michelson. The astonishing results of this experiment suggested that there is no ether drift and that light always takes the same time to cover a given distance regardless of the motion of the earth. Subsequent experiments with the interferometer and with entirely different forms of apparatus merely served to bear out the Michel-

son-Morley tests. At the same time another series of experiments, seemingly altogether unrelated to ether drift, was calling into question the principle of the conservation of matter by demonstrating that under great speeds mass contracts or grows less in quantity. Physicists were completely at a loss for a time to explain these amazing disclosures; then various suggestions were put forth, among them the Lorentz-Fitzgerald theory that under high velocities a body suffers a contraction or shortening in the direction of its motion which just compensates for time differences, just as though the train in our illustration became shorter as it moved forward, enabling the bird to cover its length in exactly the same time as when the train was standing still.

There the matter rested till 1905, when Einstein brought together the accumulated testimony and published the first part of his speculations on relativity. The velocity of light he regarded as a constant factor, and the ether he viewed as a gratuitous assumption. Since that time many physicists have come to believe that there is no such thing as an ether and that light and other forms of energy simply create their own special ether-like media as they move through space, much as current electricity creates a surrounding magnetic field.

A recent set of experiments on ether-drift has, however, tended to contradict the earlier results. With an elaborated and more delicate interferometer, Professor Miller, another American physicist, completed in 1925 a series of extended investigations on Mount Wilson in California, the results of which seem to indicate that there is after all a very definite ether-drift. Again the question of the existence of the ether has come into the lime-light, despite the fact that another physicist (Professor Tomaschek of Heidelberg) has likewise made a recent experiment at a high altitude with results quite at variance with Miller's and completely

confirming the idea that no drift exists. Still further observations are evidently necessary, and in the meantime our conceptions of the ether and its possible non-existence must hang in the balance.

With the publication of Professor Miller's findings it has been erroneously assumed in some quarters that Einstein's hypotheses may soon be discarded. Nothing could be farther from the truth with respect to relativity as commonly understood. Einstein has, in fact, enunciated two theories, a special form based upon the results of earlier ether-drift experiments and a general form based on entirely different grounds, the latter being by far the more important of the two. It is the special theory that has been called into question by Miller's recent experiments; the general form not only remains unaffected but has been verified in at least four crucial tests.

The first of these tests of the general theory of relativity had to do with the discrepancies in the movements of the planet Mercury, which the Newtonian formula failed to clarify. Regarding these, the Einstein explanation has now been generally accepted as completely satisfactory. The second and third tests were in the nature of predictions: one that a beam of light passing by a heavy body like the sun should be deflected out of its straight-line path by a greater amount than had been allowed for by Newton; and the other that there should be a definite shift in certain lines of the solar spectrum, a shift unprovided for by accepted theories. Both these predictions have also been fully verified. A fourth test carried out a few years ago by the Bureau of Standards of the United States is probably the most conclusive of them all, since it aimed directly at the central assumption of the general theory; namely, that gravity and inertia are identical. This test, the results of

which were likewise confirmatory, is too technical to be described here.

Einstein's general theory assumes that not only length and mass but time suffers a contraction in the direction of motion and that weight increases with velocity. The reason such facts have escaped us hitherto, he says, is because we have had no occasion until recently to observe matter (such as the electron) moving under enormous speeds. For all ordinary velocities the contractions and additions experienced are so infinitesimal that the most delicate of instruments would fail to detect them. Nevertheless, the temporal, spatial, and material characteristics involved in any happening or event depend very intimately on its nature, and especially on whether the movement involved is fast or slow. Time, space, and matter must, in short, be regarded as subordinate or relative to the *event*, if a correct understanding of the physical universe is to be secured.

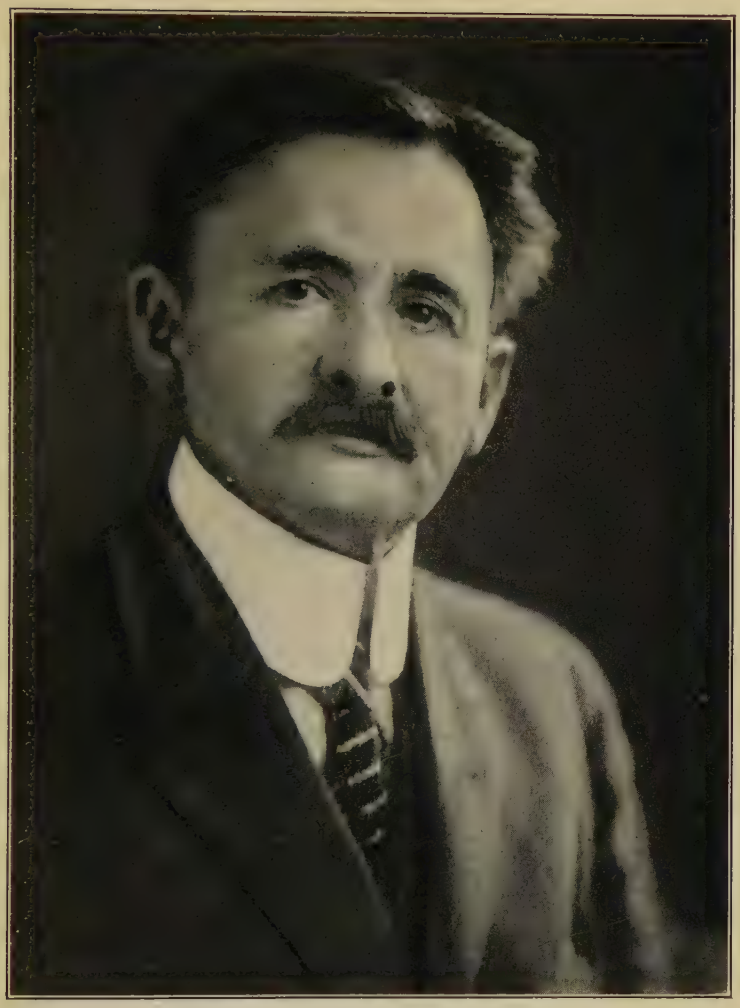
We are in these days all somewhat familiar with the idea of relativity. It has been illustrated by the flight of the bird relative to the movement of the train. If I walk down the street I can observe my progress relative to the houses I pass, but I have other motions too, while thus perambulating, of which I would be totally unaware except for a knowledge of a wider group of relationships. As the earth turns on its axis, as it winds its way around the sun, as it moves with the rest of the solar system toward Hercules or Draco, I go with it, my resultant motion being a complicated curve and my speed of transit very great. Just as my movement down the street is measured with relation to the houses, so the earth's motions are relative to the sun, and the solar system's movement is relative to some outside constellation. Einstein incorporates these conceptions into his general theory, so that no matter what point of comparison

or "frame of reference" you assume your results will hold true. His chief criticisms of Newton are that some of Newton's assumptions are superfluous (such as his separation of inertia and gravity, which Einstein considers to be one and the same), and that his formulæ, being based on the idea that time, space, and matter are independent of one another, apply to a limited class of happenings only and break down completely when enormous velocities are reached.

In making the happening or event fundamental, Einstein notes from observational data that there exists a relationship between time, space, and matter which is invariable under all circumstances. It is this relationship, expressed in convenient mathematical form, which he places at the center of his general theory. Though still somewhat incomplete, his hypothesis explains all that Newton explained as well as the discrepancies he failed to elucidate, and bids fair to bring about a very thorough recasting of our ideas of matter, energy, space, and time. These conceptions are now in the melting-pot.

§ 5

It was once thought that the stuff out of which earthly matter is made is essentially different from that which composes the stars. The ancients, to be sure, talked of the earth as a microcosm (little world) reflecting in minute detail the universe or macrocosm (great world); but this conception was wholly mystical and went hand in hand with the idea that celestial matter and movement are altogether at variance with terrestrial ones. These notions have been completely discredited in modern times. The earth is quite evidently of one piece with the rest of the universe, the elements discernible on the remotest star being identical in the main with those discoverable on our own sphere; and the



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structure and orbital motions of the atom run parallel to an amazing degree with those of the solar system, in which the earth is to the sun what the electron is to the proton. Atom and cosmos reveal the craftsmanship of the same designer.

It marked a new era for astronomy—the last of the fields under review in these two chapters on modern physical advance—when Galileo pointed his "glass" toward the heavens and brought them immeasurably nearer. The telescope gave astronomers an additional sense and caused them to turn from mathematical to physical interests. With Copernicus and Kepler an adequate perspective of geometrical positions and orbital movements had been secured, even though the accurate calculation of stellar distances could not be made till much later. Astrophysical problems took on a still wider scope with Newton's discovery of the dynamics of the universe and the launching of Laplace's nebular hypothesis to explain the evolution of the solar system.

With the invention of the spectroscope and the development of other methods of chemical analysis, the interests of astronomy widened once more, and questions regarding the constitution of the heavenly bodies were raised. The light and heat from the sun and stars came under closer scrutiny. Still more recently, geological and biological questions have taken shape, such as the oft-repeated query regarding the possibility of life on Mars. With additional instruments, such problems may some day be penetrated, though they are at present entirely beyond us. But the physics and the chemistry of the universe have for some time been within our reach, and marked progress in these directions has resulted.

The spectroscope was especially important in opening up unexplored territory for astronomy. Like the telescope

it provided astronomers with a new faculty. Following hard upon this development came in the second half of the last century the application of photography to astronomical research. This made for a still more accurate recording of observations and the simultaneous registration of a number of star positions which had previously been recorded one at a time only. Fastened to the end of a telescope and operated by delicate machinery, the star camera has revolutionized many branches of precise record-keeping in astronomy. Finally, from the days of the Herschels onward, astronomical instruments have steadily increased in size until in recent years we have witnessed the rise of immense observatories, like the Yerkes Observatory at the University of Chicago, whose dome is almost as large as the inner dome of the Cathedral of St. Paul in London, or the Mount Wilson Observatory in California, six thousand feet above the level of the sea. Only the financial resources of modern capitalism could have made such observatories possible. Their equipment is elaborate, and the mechanisms used are of most intricate and delicate design.

Even the less pretentious of modern observatories have many departments and a bewildering array of equipment. There is usually a department of meridian observation, fitted with a special type of telescope for accurately locating the positions of stars as they cross the meridian. From these observations star-catalogues are made and our clocks are kept in tune with the heavens. Another regular department is that of the equatorial, in which are used telescopes driven by clockwork, to keep a star always within the field of vision, and equipped for both visual and photographic purposes. Here we find specialists engaged in charting the heavens and measuring the star positions indicated on the photographs, in which connection an international system of coöperation between observatories has in late years been

organized. A third routine department has to do with astrophysics and astrochemistry. Here telescopic, photographic, and spectroscopic instruments combine to provide the data for a physical and chemical analysis of the heavenly bodies. Sometimes additional and more elaborate instruments are also installed in this department, and attempts are made to reproduce on earth the conditions presumed to exist on the stars in order that strange spectra may be the better understood. A fourth department is devoted to solar physics. The sun is humanity's most important star, and its detailed study is beginning to bring results which apply intimately to the current affairs of mankind. In this department are found highly specialized forms of telescopes, spectroscopes, and other instruments and methods of photography and analysis.

How much astronomy in these latter days is dependent upon physics and chemistry is fully apparent from this brief glimpse into the modern observatory with its intricate equipment. We cannot in this book even begin to point out the notable recent progress in the study of the moon, planets, Milky Way, and of comets, meteors, and nebulæ, which these observatories have fostered. What has been accomplished with respect to the remote stars and the sun will be outlined as indicative of the rest, leaving it to the interested reader to go further in one of the many popular treatises on astronomy that are available.

§ 6

After the unsuccessful attempts of Bradley and Herschel in the eighteenth century to measure stellar distances—unsuccessful because their instruments were inadequate—no progress was made in this direction until the heliometer (a device for measuring short arcs) was invented in the first half of the nineteenth century. Even then the process of

calculating what are called star parallaxes was a very tedious and laborious one—how laborious may be appreciated from the fact that less than forty star distances had been accurately determined by the end of the last century, whereas nearly two thousand have been determined since then; that is, since the spectroscope and photography have been applied to the problem. So far as star problems go, this achievement of the spectroscope is but the latest of a long series of its successes. As Professor Schlesinger of Yale tersely expresses it: "We can now tell from a study of the spectrum of a celestial object what known elements enter into its composition; whether it is gaseous or stellar; if the latter, whether it is single or double; . . . the rate at which it is approaching or receding from the solar system; its approximate temperature; and now finally its distance."

What has recently been added to our knowledge of the remote stars is considerable. Yet this is of minor consequence compared with what has transpired and what we may hope for with respect to a knowledge of the sun, which is so much nearer to us, and which, after all, furnishes astronomers with the only adequate laboratory they possess. In this solar workroom can be observed chemical changes on a scale and at pressures and temperatures impossible of imitation in terrestrial laboratories. The sun is, furthermore, both the great super-power-house of the solar system and the storehouse of energy which supplies the earth with its means of organic existence. For these reasons, the study of the sun has taken on considerable proportions.

For two centuries after Galileo discovered a number of dark regions on the solar disk which he called sun-spots, little was added to our knowledge regarding them. Then in 1826 Schwabe "began to observe them on every clear day with a small telescope, and continued to do so for nearly half a century. He found that in some years hardly a spot

was to be seen, while in others the sun's face always showed a number of them." Through his painstaking observations the now well known eleven-year cycle of sun-spots was discovered. The same length of cycle has since been found to apply to the aberrations of the magnetic compass, to the aurora borealis, to the sun's corona, and to other happenings which may or may not have a connection with the spots of the sun. If the eleven-year cycle for all these phenomena is a mere coincidence, however, it is, to say the least, a most remarkable one.

With the perfection of the spectroscope, it has been demonstrated further that the spots of the sun are the centers of strong fields of magnetic attraction, that they occur in groupings with north and south affinities, that they first appear at the poles, and, as they increase in number in their eleven-year cycle, that they move toward the equator. Through the study of its spots and otherwise, astronomers have found that the sun does not rotate on its axis as a unit but that different parts of its surface move at different rates of speed. A recent theory has it, in fact, that the sun is not a body like the earth at all but instead is a vast gaseous vortex, which lacks uniformity of movement not only at its surface but, also, as between the surface as a whole and the interior, the center spinning much more rapidly than the outside. The sun is after all a body of no great compactness or density, especially as compared with one recently discovered star, Comes, which is apparently nearly three thousand times as dense as platinum, the heaviest material known on earth.

An understanding of the heavens has from earliest times meant much for human welfare, especially in making possible the accurate foretelling of seasonal changes and the timely planting and harvesting of crops. In addition, the precise calculation of time variations and the frequent ad-

justment of timepieces have become increasingly important as civilization has advanced. Railways, steamships, telegraphs, and other twentieth-century means of communication demand uniformity in this respect. Thanks to the astronomer and the modern observatory, time signals are now sent out at stated intervals of day and night, through wireless stations situated in Europe, America, and elsewhere, and the millions upon millions of chronometers the world over are kept in tune with the universe and with one another. Ships' officers far out at sea or pilots high in the air are thus enabled to determine their positions.

The most important application of astronomical science to everyday life, however, lies in a widening knowledge of the sun and its characteristics. As this passage is being written news comes of the selection of a mountain spot on Mount Brukkaros among the Hottentots of Southwest Africa, where fifty-two hundred feet above the level of the sea the Smithsonian Institution of Washington will establish an observatory for the study of solar radiations, on the basis of which it is anticipated that long-range weather forecasting will be made more practicable.

The Smithsonian Institution has already done notable work in this regard. After three decades of study, its directors have concluded that the sun's heat and light suffer changes from day to day which reflect themselves directly in the earth's atmosphere, and that an accurate determination of these changes is of the first importance for mankind. The new solar observatory to be established in a barren crater on Mount Brukkaros, where sixty miles from a fair-sized town two American observers will live for three years measuring the sun's rays, is the third Smithsonian venture in this field. Of its two already established solar observatories, one is on Mount Whitney in California and the other in Chile. It is planned that by the spring of 1927 daily

reports from the Mount Brukkaros station in Africa will begin to reach Washington, where comparisons will be made with similar reports already arriving from the south and the west. The combined result of these observations will, it is hoped, bring about accurate predictions of weather changes weeks and even months in advance.

Such an ultimate long-range foreknowledge of the earth's weather would be of immediate benefit to man in a number of directions. Radiations from the sun affect essential crops, and over vast areas there are recurring lean years which still bring hardship to millions of people. In solar physics lies the hope of predicting when these years of scarcity are due and of giving man the opportunity to prepare his resources to meet them. Not only will farmers and business men benefit, but sailors and airmen and even tourists will be able to plan their journeys with considerably less inconvenience and peril.

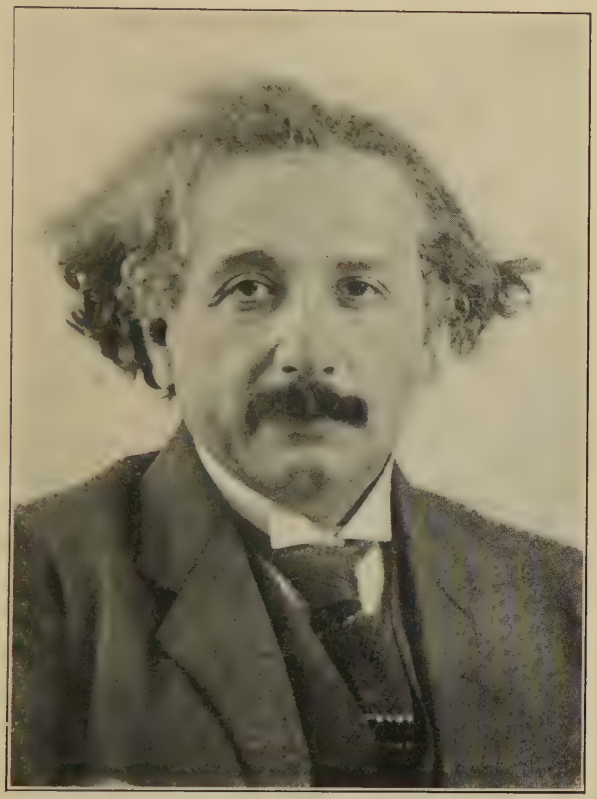
These evidences of man's utilization of astronomical knowledge by no means exhaust its possibilities. The effects of sun-spots upon terrestrial conditions and of the near approach of a planet like Mars are still to be satisfactorily evaluated, as are other celestial influences only vaguely apprehended as yet. On the other hand, the rotation of the earth on its axis, the positions of the moon and the ebb and flow of the tides, the wind and rain and ocean currents, earthquakes and volcanic eruptions, the topographic features of the earth's crust, the distribution of its natural resources, the condition of its interior, and like phenomena —the significance of which for man's welfare is much more certainly known—require the aid of the astronomer as well as that of other physical scientists for their complete understanding. Some of these phenomena will be considered in greater detail presently, for they belong even more to the field of geology than to that of astronomy.

§ 7

In the preceding chapter an account was given of the marvelous control secured by man over his environment through discoveries and inventions in physics, especially those having to do with steam, electric, and gasoline power. In the present chapter it has been indicated how the new science of chemistry is now competing with physics in this respect. A chemical revolution is developing close on the heels of the mechanical. It is also apparent that astronomy has been and is providing an additional mastery over nature. Modern physical science has in truth multiplied man's power tremendously.

There are many reasons, moreover, for believing that the harnessing of material resources has by no means spent itself. Man's call upon the cosmos—and here the practical applications of geology must be added to those of astronomy—has, it appears, only begun. With respect to chemistry and physics, he is daily finding new ways of utilizing the more common forms of energy; and he continues to believe that the tremendous resources locked fast in the atom will, through the efforts of the physical scientists and the mathematicians, one day become amenable to his control.

Nineteenth and twentieth century physical science has steadily converged toward a better understanding of chemical, atomic, and cosmic energy. The demise of the imponderables, and the completion of the last of the great physical syntheses which reduced electricity, magnetism, heat, and light to modes of motion in a supposititious ether, were the prelude. These accomplishments, together with the enunciation of the atomic theory, the isolation of the elements, the accurate determination of their atomic weights, and the discovery of the periodic law, forced physicists and chemists to realize more and more that the atom could not



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possibly be the last word in material subdivision and that energy manifestations must take their rise in intra-atomic activity. The romantic discoveries of the X-ray, radioactivity, and the electron vindicated this belief and enabled the physical scientists to penetrate the mysteries of atomic structure, where an amazing new world of countless millions of miniature solar systems stood revealed, the number of particles revolving about each central nucleus remaining as the only distinguishing mark between elements. No longer dead substance, the atom had become a veritable font of power. Sound, electricity, magnetism, heat, light, X-rays, radioactivity, Millikan rays, and other yet undiscovered forms might readily emanate from such an illimitable source. The convergence of interest had proceeded far and rapidly to disclose the atomic fountainhead from which energy manifestations spring.

To be sure, the second line of approach to this most fascinating of modern physical problems did not bring results. The medium in which most of these energy manifestations were supposed to be carried, namely, the ether, refused to divulge its secrets. Finally the Michelson-Morley experiment threw doubt on its very existence, and Einstein's hypotheses treat it as an unnecessary encumbrance. Here the physicists appear to be no further along than they were in 1873 when Maxwell published his electromagnetic theory, despite their increasing dependence upon the ether's supposed all-pervasiveness to explain many of the phenomena their science embraces. If Planck's quantum hypothesis is fully substantiated, and energy comes to be regarded as emitted not continuously but intermittently, Maxwell's great work must resolve itself into a decidedly preliminary generalization built upon partially false premises. It appears now that the ether is simply another imponderable, but such a conclusion helps us little, for how

energy is conserved in being projected through millions of miles of space remains unexplained.

Furthermore, in endeavoring to secure a better understanding of energy, our old friend matter, which no scientist had seriously questioned before the atom divulged its composition, has become decidedly self-conscious and elusive. Material in one breath and immaterial in another, the electron appears to have brought with it problems at least as profound as those it is supposed to have solved. Nor has the situation become any clearer with the discovery that matter shrinks in size and adds to its weight as its speed increases and that there exists a star of such density that a small bottle filled with its substance—and a gas at that—would weigh ten to fifteen tons!

It is such amazing disclosures which it was sought to explain by the Lorentz-Fitzgerald suggestion that length contracts in the direction of motion and the Einstein formula that matter, space, and time are relative to the event. These hypotheses and others to like effect seem now but a few more halting efforts to comprehend a physical universe still beyond man's understanding. But progress here is in no sense at a standstill, and there is every reason to believe that another burst of discovery may at any moment clarify the newer physical problems, just as the Romance of the Nineties clarified the meaning of atomic structure.

In all this, however, there is certainly no occasion for discouragement. Man has already harnessed the material resources of the universe in unprecedented fashion, with only the most preliminary understanding of the relation of matter to energy. Long before he finds a completely satisfactory explanation of this relationship and of the truer scientific significance of space and time, he may find it possible to release the vast storehouse of energy held fast in the atom and make it obedient to his will.

In the face of the mysteries and resources of the physical universe, the seeker after truth should be taught humility. Those who still so glibly prate of materialism (whatever that may now mean) as explanatory of cosmic activity, and arrogantly scoff at so-called vitalism and every other hypothesis which takes issue with their mechanistic preconceptions, are tyros indeed! We remain on the threshold of human understanding. Nor can the physical sciences alone explain this wondrous universe to us. For if the relation of matter to energy is baffling, the relation of these to vital processes and to the mind is more baffling still.

Up to this point we have indicated how far man has mastered the contents of the Book of Nature as a result of the breaking of its first four seals. Others have been torn away in the past century. What lies under the last three it will now be our purpose to examine.

CHAPTER XI

MODERN GEOLOGY

§ 1

THE science of geology, which investigates the inorganic constitution of the earth through an intelligent observation and interpretation of rocks, fossils, and large-scale natural formations, is essentially a nineteenth-century product. The past is rich in geologic speculation, but adequate earth facts were not forthcoming till the last fifty or seventy-five years.

The scientific exploration of our planet began after mathematics, physics, chemistry, and astronomy had established the foundation facts of the physical universe. Astronomy deals with the general characteristics of all the heavenly bodies, including the earth. Geology concerns itself with the one planet only, entering into more intimate phases of its history and characteristics and, even here, dividing the field with its sister science biology. Physics and chemistry had to provide certain necessary tools before geology could proceed to clarify its basic conceptions and fashion itself into a science. These preliminaries were not completed till after the nineteenth century was well under way.

Nor were the colorful geological speculations of the past at all helpful. The Greeks contributed little of value, and the Middle Ages took a backward step from even this poor beginning. In the sixteenth century the ideas of Leonardo da Vinci, and in the seventeenth those of Steno, were the only ones of constructive import, and these were looked upon by contemporary thinkers as the "vaporings of disordered minds." In the eighteenth century the cold-earth, catas-

trophic-change, and special-creation misconceptions supported by Werner and sanctioned by the church held both geologists and biologists in a paralyzing grip, and the hot-earth and gradual-change theories of Hutton and Laplace were vigorously opposed by natural historians and clergy alike. Some of the latter have even to-day not yet abandoned their opposition, while geologists with few exceptions could not be turned from the dogmas of the Wernerian school till after 1830.

§ 2

During the early years of the nineteenth century, false theories regarding geological phenomena continued to have a stifling effect upon all branches of the study. The attitude of the period toward such problems as the origin and age of the earth, the creation of mountains, valleys, and plains, and the interpretation of fossils and rock forms, may be briefly indicated as illustrating the character of the ideas of natural history then generally prevalent.

With respect to the origin of the earth, Laplace's nebular hypothesis has been designated in a preceding chapter as the crowning achievement of eighteenth-century astrogeology. Yet during the first quarter of the nineteenth century it was making headway very slowly among natural historians. It received quite ready acceptance among astronomers, but since it violated the cold-earth ideas of the Wernerians, geologists for some years would have nothing of it. As for the age of the earth, a theologian in the seventeenth century had set its beginning at 4004 B.C. Though unsupported by any facts whatsoever, this date was still unquestionably accepted by most students of nature in the early nineteenth century. Along with the deluges and other presupposed catastrophes, the earth was presumed to be less than six thousand years old, and the attempt was made

to squeeze all geological processes into this short period. The fact that the age of the earth is to be found written in part in the fossil remains embedded in sedimentary rocks —the time it took for various layers to form, furnishing a basis from which the total age can be calculated—this fact was then not recognized. The theological presuppositions were in the main regarded as sufficiently "explanatory."

The idea of a ready-made earth, created less than six thousand years ago and unalterable except by catastrophic action or all-embracing deluge, also shrouded in darkness the meaning of large-scale natural formations. The physiography of the earth's surface was simply taken for granted. Mountains, valleys, streams, plains, and the like were thought to have been fashioned on the spot, in one sudden act of creation. It was in this field particularly that Hutton at the end of the eighteenth century had called attention to facts previously overlooked, going back to the excellent observational work of Desmarest and the elder Saussure. Mountains had been thought of as produced either at the original creation, or since that time by earthquakes, landslides, and floods. The Huttonian idea was that some "raising agency" is needed to account for the earth's configuration and that many existing rocks show unmistakable signs of having previously been in a molten state, but this conception was still violently opposed in the early nineteenth century. It took many more facts and much more incisive ones than Hutton had presented to break through current preconceptions. In physiography, important progress was not forthcoming till after the third decade of the century had passed.

In the interpretation of fossils, the Wernerian atmosphere was similarly inhibitory to constructive advance. To be sure, the fantastic notions of the Middle Ages that fossils are fermentations or exhalations from the soil, inor-

ganic sediments or forces, seeds from distant stars, or half-formed beings which the Creator had cast aside—such notions had been discarded at the beginning of the nineteenth century. By that time, the accumulated evidence had left no further room for doubt. Fossils had come to be recognized as the remains of organisms once living. But it was still believed that all existing animals had been created out of hand at one time and that none had since been added. Hence if no living organism could be found to match the relics unearthed—and a great number of such discrepancies disclosed themselves—it was because all-embracing floods had, from time to time, wiped out many kinds of animals. The idea of gradual change from one species to another was apparently exceedingly repugnant then, just as it is somewhat repugnant to certain poorly informed people even now. Before fossil remains could be constructively interpreted, the ideas of the Wernerians had to be discarded. In the interim the keen interest in fossil hunting, starting with the nineteenth century, paved the way for a more penetrating analysis after the proper instruments had been perfected.

Regarding an adequate understanding of rock formations, it has already been indicated at some length, in a preceding chapter, that Werner, despite his false theories, did significant pioneer work here, and that his system of classification, though artificial, was a step in advance. Werner laid the foundations for modern rock description or petrography, as it is technically called, by basing his classification upon mineral composition instead of the less satisfactory classifications that had preceded. His scheme of structural description, however, paid no attention to the age or origin of rocks, a more important phase of the subject which was developed much later. Yet the study of neither rock descriptions nor origins could be carried very far without the use of

certain analytical tools which in the early nineteenth century were still to be provided by physics and chemistry.

In all these fields of geological study—having to do with the origin and age of the earth, with the significance of mountains and valleys, and with the interpretation of fossils and rocks—the preconceptions of the eighteenth and early nineteenth centuries hampered progress. But the more significant hindrance here, as in other sciences when in a similar stage of development, lay in the inadequacy and superficial character of available facts. The gathering of more pertinent information constituted here as elsewhere the greatest impulse for the acceptance of better theories.

The basic data of geology can be broadly grouped into the three categories already mentioned: rocks, fossils, and large-scale physiographic formations. How such facts were developed into a body of knowledge worthy of the name of a science, and how physics and chemistry contributed toward this end, will now be discussed.

§ 3

Petrography, which has just been defined as rock description, preceded petrology, the study of rock origins, by about a hundred years. Beginning with Werner and continuing for the first three decades of the nineteenth century, the problem of rock classification became clarified to the extent of discarding the biological scheme of genera and species, foisted upon the inorganic realm by Linnæus, and of separating the study of rocks (petrography and petrology) from that of rock masses or strata (stratigraphy). The latter is associated more with the study of fossils than with rocks. Structural features, mineralogical constitution, and approximate chemical composition now came to be used as criteria for further helpful schemes of rock classification.

In the first third of the century a notable book appeared

which spurred geological research in all directions, including the study of rocks. Its author was an eminent Englishman, Sir Charles Lyell (1797-1875), the foremost British geologist of the nineteenth century. His "Principles of Geology," in three volumes, began appearing in 1830. It marks a distinct epoch in geological advance.

Lyell was a native of Scotland, had been educated at Oxford, and had obtained his master's degree there in 1821, continuing with the study of law till 1824, when he was admitted to the bar. His primary interest, however, was in geology. During his seven years at Oxford he had contributed such creditable scientific articles to leading technical journals that as early as 1826 he was elected a member of the Royal Society. He had also become active in the Geological Society of London, which was organized in 1807 on Baconian lines; for its founders had become disgusted with current speculations and had resolved to depend strictly on experiment and observation. In 1832, the year the second book of his great three-volume work appeared, Lyell called the ideals of the organizers of the Geological Society to the attention of all serious-minded geologists, who, he maintained, should "multiply and record observations, and patiently await the result at some future time," insisting "that the time was not yet come for a general system of geology, but that all must be content for many years to be exclusively engaged in furnishing materials for future generalizations." This emphatic statement had a marked influence upon the fact gathering of his day.

Lyell courageously allied himself with Hutton against the Wernerians and the church, and focused attention, among other things, on the need for better petrographical data. Through his influence petrographers were spurred to renewed effort, until, toward the middle of the century, the subject appeared to have been exhausted. And yet—and

here is a significant point—the facts of rock composition were then on about the same plane as were the facts of astronomy before the introduction of the telescope and the opening up of the heavens by Galileo. The analysis of the components of fine-grained rocks was beyond the reach of unaided observation, and further progress in that direction seemed impossible.

It was at this juncture that the science of physics produced the compound polarizing microscope and devised the means of preparing thin sections of fossil wood for microscopic examination. An unexplored world was thus revealed to the petrographer, and the startling discovery was forthwith made that common chalk, regarding which Huxley later wrote a famous essay, is composed of skeletons of minute organisms. By 1850 the new microscopic technique was being applied to the study of the softer rocks, and experiments were being made with the harder ones. The way had at last been found for seeing beneath surface superficialities and for assembling petrographic facts scientifically. The invention of the compound polarizing microscope and its application to petrography (rock descriptions) constituted an important step in building geology into a science.

After the first half of the century, the new petrography developed with great rapidity. A method was finally perfected for cutting from dense rock a section so thin—one one-thousandth of an inch in thickness—that a printed page might be read through it, and the minutest of structures stood revealed under magnification. Important discoveries in rock composition now followed in quick succession, and competent workers in Germany, France, England, and the United States were drawn in large numbers into this interesting field of investigation. Before the nineteenth century closed, the microscopic examination of rocks had added enormously to the facts of petrography and was raising a

whole crop of new problems, problems which centered thought increasingly upon rock origins or petrology.

In the meantime, petrology had been more or less superficially prosecuted. The early nineteenth-century controversy between the Wernerians and the Huttonians over a cold or hot earth had been finally silenced in the light of fast accumulating evidence that certain rocks show unmistakable signs of a molten origin. It had become clear that not all rocks are deposited as precipitates from oceans and streams. A hot interior for the earth became the only rational hypothesis for giving meaning to lavas and other igneous masses. About the middle of the century chemical analyses to determine rock origins reached considerable proportions, culminating in the first decade of the twentieth century in the publication of three American books which are to-day used as standard among geologists of all countries.

Yet all this static analysis was but a preliminary to the real petrological development which was to follow upon the heels of advances in physical chemistry. The most accurate description of the chemical composition of rocks cannot of itself explain their origin. Petrological dynamics had to supersede petrological statics before the processes which operate to form quartz, granite, and marble from molten masses could be understood.

The problem here was recognized long before physical chemistry had perfected its methods for carrying out experiments under high temperatures and pressures. As far back as 1800, lavas from Etna and Vesuvius had been melted and crystalline rock produced from the cooling mass. From that time on, similar experiments had been attempted at infrequent intervals, especially in France, but the handicaps had been such that only the most elementary researches along dynamic lines could be undertaken till the

very end of the century. To-day it has become possible, with improved technical equipment and methods, to reproduce in the chemical laboratory the subterranean conditions under which liquid masses originate and to observe the stages through which they pass into crystalline and other igneous rock forms. The greatest center for carrying on this study is to be found in the United States, in the Carnegie Geophysical Laboratory at Washington, "where under ideal conditions a corps of physicists, chemists, mineralogists, and petrologists are solving the deeper problems of rock genesis and rock relationship."

Petrography and petrology, the sub-sciences of rock description and origin, constitute one important department of scientific fact gathering in geology. Without the basic data thus provided, the crude theories of the early nineteenth century could not have been constructively combated.

§ 4

The proper interpretation of fossils is significant for both geology and biology. In the latter domain, the study of extinct organisms is taken care of by an important department called paleontology. Here the relation of fossils to the origin and development of living organisms is determined. It is this field of fossil study which has aroused such universal popular interest in recent years and which has led to frequent articles in metropolitan dailies upon the discoveries of the investigators now at work in all parts of the world who are bringing to light the mysteries of life in the past.

In geology, the study of fossils is of importance as indicating the various geological epochs through which the earth has passed in its development, and by which the age of the earth can be roughly calculated. This branch of geological science is designated as stratigraphy. Paleon-

tology does not concern us at present, whereas stratigraphy does; yet there are many phases of paleontological advance which are of significance to geology. The two aspects of fossil study are naturally very closely related.

The compound polarizing microscope proved a potent tool for locating and analyzing fossils embedded in earth formations just as it did for analyzing rocks. Here, also, it opened up an unexplored world. Before this instrument was perfected, however, an important discovery had been made in stratigraphy which revolutionized its entire methodology. Preceding Werner, two geologists—one in Italy and the other in Germany—had suggested that "groups of strata have definite chronological value" and that "the débris of lower strata has been utilized in building the strata next above." But the ideas of these men were regarded as fantastic by their colleagues. The way rocks are tilted, and their mineralogical and chemical composition, were looked upon at the time as the determining factors in geological age. Here the matter rested till the second decade of the nineteenth century, where William Smith (1769-1838), English civil engineer and geologist, who preceded Lyell and is known to-day as the "Father of English Geology," made the epoch-making discovery that the age of sedimentary rocks can be best determined by the type of fossils embedded in them. Sediments laid down in the same period, he pointed out, have a similar fossil content.

This discovery was no mere lucky guess. Smith was a follower of Hutton and an ardent student of nature. On his surveying trips into various parts of England, he made notations in his field-books regarding "the position, extent, and composition of sedimentary rocks" and the character of the fossils occurring in each stratum. On his geological maps he recorded these observations in colors and noted that the same relics reappear in similar sedimentary beds in

different localities. From these facts he drew the important generalization that "each fossil species is entombed in a definite sedimentary formation."

Smith published his findings in 1815. The importance of his work was immediately recognized in England, where a number of capable students carried it further. In Lyell's "Principles," which began appearing fifteen years later, Smith's discovery was incorporated and was thus made available to the whole world of geological science, for Lyell's book had a wide distribution. By the end of the first half of the century, English stratigraphers had already "developed a time-scale by which the relative age of all the sedimentary and igneous rocks of the world could be measured." This was a notable achievement and, together with the application of the polarizing microscope, spurred stratigraphic research tremendously. With Lyell's book, in which a firm stand was taken in favor of slow and orderly development, or uniformitarianism as it is called, the catastrophic and special-creation theories received their death-blow so far as the science of geology was concerned. Lyell made the facts of stratigraphy speak for themselves. To quote his own words: "When species [of fossils] are arranged in a series and placed near to each other with due regard to their natural affinities, they each differ in so minute a degree from those next joining that they almost melt into each other." Once more the facts proved stronger than preconceived notions. With the firm establishment of stratigraphy, a second important corner-stone of the science of geology was laid, the first consisting in the already mentioned application of the microscope to the scientific study of rocks in petrography and petrology.

During the second half of the nineteenth century, stratigraphic investigation bore out still more completely the findings of Hutton, Smith, and Lyell. Tens of thousands of

additional fossil remains were discovered, and many gaps in the sedimentary record were filled in. By far the greatest recent contributions to the stratigraphic history of the earth have come from the United States, where state and federal surveys and university researches have been particularly active. The last twenty-five years have seen a still further expansion of this work in the direction of reconstructing the conditions of wind, climate, rainfall, streams, mountains, lands, and seas, which existed during various geological periods. Maps and physical geographies of these early epochs are being prepared. All in all, this phase of geological investigation promises to become one of the most interesting and important developments of the twentieth century.

After the publication of Lyell's epoch-making treatise (1830-1833) and the discrediting of the catastrophists, geologists turned in earnest to the problem of determining the age of the earth. The period of about six thousand years, the assumption of the theologians, became a mere day in the eon of geological time which seemed to be necessary to account for the formation of the sedimentary strata. The opposition of the ecclesiastics continued unabated, but the stubborn facts left room for only one rational answer; namely, that it must have taken many millions rather than a few thousands of years for the earth to pass through the various stages written in the sedimentary rocks. The main stratigraphic eras were broken up into a number of subdivisions, each of which made considerable drafts upon time. A hundred million years seemed little enough to allow for the earth's age.

Somewhat later the facts of stratigraphy began to run counter to the teachings of physics. Lord Kelvin submitted mathematical evidence that the sun could not have been sending forth heat for more than a hundred million years and that the earth could not have been in existence more

than from one tenth to one fifth of that period, thus allowing only ten to twenty million years for the earth's age. For a time these figures appeared irrefutable, and geologists tried unsuccessfully to speed up terrestrial processes. Then, in 1895, a reëxamination of the physical evidence showed the weakness of Lord Kelvin's computations, and in addition radioactivity was demanding a still greater stretch of time, to account for its disintegrating effects, than the geologists were insisting upon for their purposes. To-day it is estimated that approximately one thousand million years have elapsed since rocks first appeared on the earth, and this estimate entirely omits still more ancient terrestrial conditions. The study of fossil remains has completely revolutionized our thinking with respect to the age of the earth.

§ 5

In placing geology upon a scientific basis, a third development of outstanding significance had to do with the formulation of plausible hypotheses regarding the causes of large-scale physiographic formations.

For a constructive understanding of the forces at work fashioning mountains, valleys, plains, and other features of terrestrial topography, it was essential that the basic facts of petrography, petrology, and stratigraphy be made available. Certain pertinent observations had been made at an earlier time, but the only workers who took them seriously and interpreted them correctly were the Huttonians, whose views were regarded by the great majority of the geologists of their day as "monstrosities." Had it not been for the clear-sighted vision and fearless aggressiveness of Lyell, physiographic progress would also have been delayed much longer than it was.

In 1828 Lyell had made an extensive trip through Europe, during which he was struck with the many unmis-

LYELL

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takable evidences in Sicily "of the slow but steady elevation of that island from the sea." He had found further confirmation in England, Germany, and Scotland of Hutton's contentions that a subterranean lifting agency is at work and that geological changes occur gradually and over long periods of time rather than cataclysmically. These evidences of terrestrial dynamics decided Lyell upon his course of silencing the Wernerians with the unassailable array of facts which he began publishing in his three-volume treatise two years later. His extensive travels, including two lecture tours in the United States, gave him a wide contact with scholars and with the general public of many countries, in addition to splendid opportunities for comprehensive observation. Furthermore, his simple and interesting style, in oral and written language alike, make him exceedingly popular. So great was his influence and so widespread the demand for his text that within a decade after its publication the Wernerians and the ecclesiastics were decidedly on the defensive when it came to questions of geology. Twenty years later a similar struggle between deeply rooted prejudice and the newly born science of biology came into the ascendency; and once again Lyell entered the lists.

His contributions to science are indeed great. Nor did his services pass unrecognized. During his lifetime, he was the recipient of honors from many scientific societies in a number of countries. His own land was foremost in this recognition, for he had barely passed fifty when England knighted him; later he received a baronetcy.

As Wernerian tenets came to be discarded, constructive hypotheses as to the earth's topography were launched. The Huttonian theory that "forces operating on and within the earth during past time are the same as those of to-day and that knowledge of past events is to be gained by studying present processes" now came to the fore. Further fact-

gathering soon made it apparent that "the building of mountains and continents, the folding and breaking of strata, the making of igneous and sedimentary rocks, the entombing of fossils," and the erosion of plains into valleys are taking place now just as they did in bygone ages. All these processes are orderly and uniform. By observing what is happening to-day, much of the geological history of the past can be understood, and as for the rest, the rocks and the strata tell a fairly connected story.

Following Lyell, the geologist most responsible for establishing the modern hypothesis of mountain and valley origins was James D. Dana (1813-1895), an American of New England ancestry. Dana, after graduating from Yale at twenty, became interested in the geology of the Pacific, while associated with the United States Navy as an instructor and later as a member of a government exploring expedition. He made wide observations on his tours, collecting many specimens of corals and shell-fish, and reported on volcanoes in the Sandwich Islands, the positions of coral-reefs in the Pacific, and the formation of valleys in New South Wales. Two important treatises published in 1850 grew out of these investigations. Immediately afterward he was appointed professor of geology at Yale, where he served for forty-five years. In 1863 he published a notable text-book which went through a number of editions. His services to science were recognized in his appointment to membership in the Royal Society of London and similar societies in Paris, Berlin, Vienna, and St. Petersburg. He was also awarded the Wollaston and Copley medals in England and was actively associated with the American Association for the Advancement of Science, of which he was the president as early as 1854.

Dana's valley-formation theory grew out of the ideas

expressed more than half a century before by Hutton and his two predecessors (Desmarest and the elder Saussure), that valleys are produced by the erosive action of rivers. These early ideas had been well buttressed by observation, but they had, here as elsewhere, been submerged by the prejudices of the catastrophists. Even Lyell, though on quite different grounds, had disagreed with the hypothesis of valleys made by stream erosion, placing emphasis upon the supposed causal connections of earthquakes, bursting of lakes, and the ebb and flow of oceans and seas. The action of running streams appeared too infinitesimal to account for the creation of deep valleys and gorges.

The observations Dana made on his tours of exploration convinced him that Hutton had been right. In one of his treatises he clearly demonstrated that valleys on the Pacific islands could not possibly owe "their origin, position, nor form to the sea," and that they are the "work of existing streams which have eaten their way headwards." He proved that the valleys of Australia are "products of normal stream action" and that many bays and inlets "are but the drowned mouths of river-made valleys." Later, after Dana's conclusions had been published, the Grand Cañon of the Colorado and the Rocky Mountain gorges were also shown to be products of stream erosion.

With the acceptance of Dana's proofs as to valley origins, the mechanics of the erosion process came to receive detailed study, many competent investigators entering upon this field of research. Thirty-five years ago, one of the ablest of these, W. M. Davis, used the following words to indicate further problems to be taken up:

> Being fully persuaded of the gradual and systematic evolution of topographical forms, it is now desired . . . to seek the causes of the location of streams in their present courses; to go back if possible to

the early date when central Pennsylvania was first raised from the sea, and trace the development of the several river systems then implanted upon it from their ancient beginning to the present time.

To-day such tasks are a part of everyday field work, for the analysis of valley formation has been undertaken on a vast scale.

It would be leading too far in the direction of technicality to indicate to what a degree of precise study this principle of erosion has led in recent times, especially in defining so-called cycles of erosion and peneplains (almost plains). To-day not only rivers but ice and wind and other factors are recognized as responsible for the sculpturing of valleys and level surfaces.

Dana's hypothesis of mountain formation likewise had its inception in Huttonian ideas. Hutton and Lyell both believed that the earth is in a hot molten or semi-fluid condition beneath the surface and that, while cooling, its face becomes wrinkled into mountain ranges by pressure from below and laterally. Dana, as a result of his extensive investigations, developed this idea further, combining it with his observations and theories of erosion. Streams carry away sediments and deposit them at various spots on the earth's surface. These gradually sink under the pressure of the deposits thus accumulated in long periods of time and eventually become deep troughs, thousands of feet in depth, filled with loose sedimentary earth. After a time, because of pressure exerted beneath the earth's surface against the bottom of these troughs and by the much harder contiguous earth against the sides, the sedimentary deposits are slowly pressed up and folded over into newborn mountain ranges. Afterward the erosive action of streams and wind and atmosphere mold out the ridges, peaks, and valleys.

This hypothesis has been increasingly borne out. The

cumulative evidence of the last seventy-five years has raised it from a plausible theory to a scientific generalization widely accepted by geologists. Many of the subterranean forces pushing and compressing the earth at various points are still not understood, but the study of mountain origins is going forward with confidence that these forces will sooner or later be fully comprehended.

There is one other important phase of large-scale topographic earth-sculpture which may profitably be taken up here. This has to do with an explanation of the presence of erratic boulders and drifts found in unexpected places and in unnatural positions on the earth's surface. The problem is well pictured in the following statement made as early as 1821 by an outstanding American chemist and geologist, Benjamin Silliman:

> The almost universal existence of rolled pebbles and boulders of rock, not only on the margin of oceans, seas, lakes, and rivers; but their existence, often in enormous quantities, in situations quite removed from large waters; inland—in high banks, imbedded in strata, or scattered, occasionally in profusion, on the face of almost every region, and sometimes on the tops and declivities of mountains, as well as in the valleys between them; their entire difference, in many cases, from the rocks in the country where they lie . . . these and a multitude of similar facts have ever struck us as being among the most interesting of geological occurrences, and as being very inadequately accounted for by existing theories.

Such phenomena were inexplicable to Lyell, and their existence caused him to view some of his own conclusions with suspicion. Here the deluge theory made its last and most effective stand, for polished boulders do seem to point to the action of water, and their almost universal occurrence would seem to indicate some cause of an all-embracing character. Yet, even here, the Wernerians were doomed to

disappointment in the rise of the glacial-drift hypothesis which explained the observed phenomena much more completely.

The man most responsible for establishing the glacial theory was Louis Agassiz (1807-1873). Born in Switzerland where the glaciers of the Alps are an ever-present physiographic wonder, Agassiz had specialized in medicine and zoölogy at the Universities of Zurich, Heidelberg, and Paris, and in 1832 had become professor of natural history at the University of Neuchâtel, Switzerland. Here, in collaboration with two other scientists of note, he devoted his summers to the study of glaciers and their movements. These investigations resulted in a number of interesting discoveries and led in 1840 to the publication of his famous "Etudes sur les Glaciers," "remarkable alike," as an authority expresses it, "for its clarity, its sound inductions, and wealth of illustrations." The work of Agassiz was of outstanding importance and led in 1846 to his appointment as professor of natural history in Harvard University, where he remained for the rest of his life. Agassiz had great charm as a lecturer and was a most popular member of the Harvard faculty.

In his book he enlarged upon the suggestions of two of his contemporaries that "the glaciers of the Alps once had greater extent," and put forth the bold assumption "that the surface of Europe as far south as the shores of the Mediterranean and Caspian seas was covered by ice during a period immediately preceding the present." About a decade and a half before this treatise appeared, two Americans (Granger and Dobson) had insisted that water could not have produced the glassy smoothness and clean-cut grooves in the rock surfaces and the polished boulders found along the shores of Lake Erie and in the Connecticut valley, and that some hard body, such as ice, must have

been instrumental. As part of his assumption, Agassiz maintained that glacial drift constitutes this hard and powerful agency of attrition and supported his belief with numerous observational proofs.

These ideas brought Agassiz into prominence and aroused a violent controversy, just as Lyell's book had done ten years before, but in this dispute the deluge advocates were not so easily silenced. It required a stretch of the imagination to believe that the earth's climate had recently been frigid enough to maintain "glaciers of continental dimensions"; and, with fossil evidence not yet sufficiently available, "the great polar ice sheets unexplored," and the difference between glacial till and water-laid drift not yet made clear, the objections to the glacial theory were at first formidable. Thirty-five years passed before it became fully established and the proponents of deluges in this connection were silenced.

After it became clearly evident that the glacial hypothesis squares itself with all known facts of relevance and that no alternative theory explains the observed phenomena, geologists took up in earnest the investigation of the extent of glacial drift. Many field studies for this purpose have been undertaken in the last fifty years, and maps of terrestrial areas, over which at one time or another glaciers are supposed to have moved, have been plotted. It is now definitely established that the earth has experienced not one but a number of glacial ages or periods. Several advances and retreats in America and in Europe have been somewhat clearly delineated, and the distinguishing features of the intervening or interglacial epochs have also been worked out.

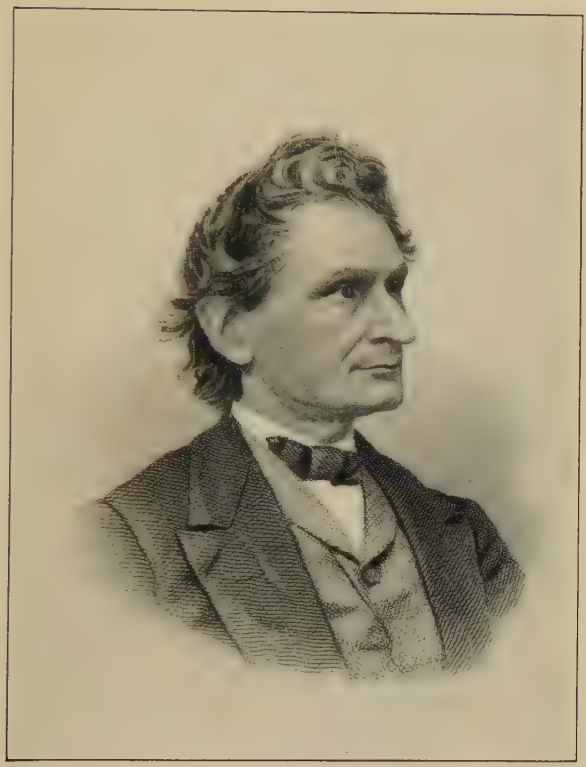
It is to-day universally recognized that moving ice has erosive power just as running water has, but to a markedly greater degree. "Flat-floored, steep-walled gorges, hanging

valleys," and peculiarly constructed lake basins are being explained as due to glacial drift.

Taking it all in all, the process of erosion is apparently one of two major processes of earth sculpture, the other being the subterranean process which results in wrinkling, folding, and lifting the earth's crust. Erosion carves out the vast majority of terrestrial configurations, not by one medium alone, but by falling rain and snow, by winds, by rivers and streams, and by glacial ice. These are indicated in the order of their potency, the most potent being mentioned last. Rain and snow have some erosive effect. Wind has much more (to quote Van Wagenen in his "Beacon Lights of Science"), "piling up dunes in arid regions and along sea shores, and occasionally in confined areas acting like the familiar sand blast in sculpturing rocks into all kinds of fantastic shapes. The work done by the rivers and streams is necessarily confined to the deepening of their channels and the creation of bars along their sides. . . . The ice, however, is the great erosive agent, and no more impressive exhibition of its capacity in that line is to be found than in the northern parts of the North American continent, where the great sheets of the last glacial era have worn away . . . sedimentary rocks over hundreds of thousands of square miles of area, and carried the vast cargo of sand, gravel, and boulders southward across the Canadian border into the United States, finally dropping it in the form of a terminal moraine over two thousand miles in length, which to-day constitutes the southern divide of the St. Lawrence valley and the Great Lakes."

Erosion and subterranean pressure, these are the main keys which unlock the door to the origin of mountains and valleys, continents and oceans, volcanoes and earthquakes, and other features of the earth's topography.

The meaning of the statement, made at the beginning



DANA

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of this chapter, that geology is essentially a nineteenth-century product, is now more fully apparent. The application of the polarizing microscope to rock and fossil studies, the contributions of Lyell in cutting away the underbrush of false conceptions and in marking out the road to constructive advance, the revolutionary generalizations of Smith in stratigraphy, of Dana as to mountain and valley origins, and of Agassiz regarding glacial drift—these achievements occurred between the third and fifth decades of the nineteenth century. Taken as a whole, along with the earlier work of Hutton and Laplace, they placed geology upon a scientific basis. They broke the fifth Seal of Science.

§ 6

The various problems geology endeavors to solve have an entirely different complexion at the beginning of the second quarter of the twentieth century than they had a hundred years ago. Whereas at that time Laplace's nebular hypothesis was regarded by most geologists as an impiety and a disjointed fiction, it is now an integral though somewhat modified part of a much more comprehensive generalization including not only the origin of the earth but its gradual and progressive development through a thousand million years of inorganic and organic existence. Thirteen or more geologic periods, the shortest of them several thousand times as long as the entire age of the earth was then presumed to be, have now been clearly deciphered in the fossil remains embedded in stratified sedimentary rocks. The physiography of the earth's surface, then looked upon as having been sculptured in one grand gesture out of hand, is now seen as the work of subterranean processes wrinkling or squeezing the surface into ocean beds and mountain ranges, and of slow erosive forces of rain, wind, river, and

glacier, which through countless ages have shaped and reshaped its topography. Rocks were then very superficially classified; they are now examined minutely under improved forms of magnifying instruments and are subjected to enormous pressures and high temperatures to reproduce the conditions of their origin and the stages through which they passed into their present forms. Chemical analysis of rocks is now a commonplace, whereas then it was virtually unheard of. And, finally, fossil remains, then regarded as representing fixed and unalterable species all created at one time, are now clearly recognized as the relics of organisms which developed from simpler to ever more complex forms until the highly organized species of the modern world were evolved.

With respect to the earth's development, it has become increasingly evident that there has been no marked cooling of the surface for countless ages. There have been many changes of temperature, but the average or mean temperature has apparently remained about the same. Neither has there been any general decline in the intensity of volcanic action, although there have been alternations between periods of widespread volcanic activity and periods of comparative repose. Nor has the atmosphere of the earth changed very much from remote antiquity. In short, geologic evidence indicates that the forces working within and upon the earth now are the same as throughout the ages with which geology concerns itself.

All this appears to run counter to the idea that the earth was once a hot gaseous nebula which has gradually cooled to its present form. The planetesimal or meteoric dust theory of the earth's origin would seem to square better with the facts. And yet there is no necessary discrepancy. It may be that geology has record only of a period following the cooling of the earth to its present

condition, which might be regarded as one of equilibrium, no further changes occurring throughout geologic time. Be that as it may, the origin of the earth is more a problem for astronomy than for geology, though whatever theory is accepted must conform to the geologic record.

Geology as yet knows little of a direct nature regarding the earth beyond a very thin crust, underneath which is a vast unexplored region. The deepest mine borings are less than two miles deep, and it is four thousand miles to the center. It is quite hot even at the depth of a mile, and the materials there are much as they are on the earth's surface.

We do, however, know something of the earth's interior from indirect evidence, physical, seismological, and otherwise. It has been shown that the average density of the earth is more than twice that of the rocks found on its surface. The material inside must be much heavier therefore than that on the outside. There is reason to believe that the central mass consists chiefly of metals, probably a combination of iron and nickel, which is the composition of the metallic meteorites constantly falling to earth, whereas in the main the crust is composed of stone. That the earth's interior is in a superheated, fluidifiable state is amply evidenced by the actions of geysers and volcanoes, the origin of which has likewise been made more completely intelligible in recent years.

The earth has come to be thought of as consisting of four main layers or spheres: the inner metallic core, about seventy-eight hundred miles in diameter, called the barysphere; the relatively thin surface or rocky crust known as the lithosphere; the waters which rest upon this surface, designated the hydrosphere; and the outermost layer or zone of gas composing the atmosphere.

Any one familiar with the process of puddling molten iron, through which a stony scale or slag is brought to the

top, will readily understand the procedure by which it is thought by some authorities that the lighter stony elements of the earth were gradually separated from the superheated, fluidifiable nickel-iron mass in the earth's interior and pushed to the surface to form its crust. As the crust cooled, according to this theory, the moisture and gases collected on the surface or escaped upward, thus forming the outer spheres.

But the separation of the earth into its four great layers did not complete the geologic process, for the attack upon the lithosphere through the erosive action of the two outer zones must have begun immediately. The molten rock-masses forced up from the earth's interior to form its crust are the so-called primary rocks. Those portions of the surface carried away by erosive action and deposited elsewhere are secondary.

The distinction between primary and secondary rocks is of highest importance for modern geological research. The primary rocks show unmistakable evidence of an igneous origin. As they were produced under high temperatures, no living organism could have been present at their formation. Hence they contain no fossil remains. They are unfossiliferous. Again, they were crystallized out of a molten mass, not laid down in strata. Therefore, they are always unstratified.

Secondary rocks fall into three chief categories: fragmentary or broken primary masses called clastic rocks; organic rocks composed of the remains of animals or plants; and chemically formed masses which are compounded by chemical processes out of older forms. Secondary rocks are fossiliferous. Having been carried away and deposited at various points of the earth's surface, they contain fossil relics of plants and animals living at the time of their deposition. Secondary rocks are also stratified, since they

were laid down in successive laminations or layers following the conditions existing on the earth at different periods of geologic history. Deposits made on land are different from those made on the floors of oceans and seas, the latter falling into one of two groups: they are either the red clays which are composed of fragments of rock dust carried out to sea by the winds and there deposited, or they are the type of ooze or sea-mud composed chiefly of the remains of microscopic marine plants and animals. Beds of chalk belong to the second group.

The erosive and denuding action of the atmosphere and hydrosphere, through wind, rain, rivers, sea, and ice, has not only sculptured the surface of the earth into extremely irregular shapes but has also tended "to destroy the rocks, wear away the land, and sweep the materials into the sea," which action, if there were no opposing force, would in time level the hills and mountains and fill up the oceans. This denuding activity goes on very rapidly. Gases of the air combine with rock constituents and produce an expansion which aids in the crumbling process. Rain then washes the crumbled portions away, exposing fresh surfaces to the action of the atmosphere. During periods of frost, the water that has seeped into the crevices of rocks hardens into ice and in freezing expands and helps burst the rocks asunder. Expansion and contraction of the rocks themselves, following changes in temperature, work toward the same end. Strong winds aid in the destructive process, having the effect of the familiar sand-blast, which is now extensively used to renovate old stone buildings. The action of rivers, torrential streams, and glaciers has been sufficiently stressed. The hydrosphere and atmosphere form an aggressive alliance whose object is to wear down and level off the lithosphere.

This alliance, however, finds a worthy antagonist in the

barysphere, which has ideas of its own as to the configuration of the earth's surface. Opposing the action of the atmosphere and hydrosphere, it lifts up continents and lowers the floors of oceans. As if in anger on occasion, it causes the earth to tremble and quake and belches forth lava from its volcanoes. Furthermore, the barysphere alternates, it appears, between moods of contraction and expansion, as a result of which the lithospheric crust is buckled and corrugated and in places breaks into faults.

The major disturbances of the earth's surface which are felt as earthquakes are well known. There are also lesser perturbations which are constantly occurring but which can only be perceived by means of delicate instruments. The earth in turning about its axis may be likened to a gigantic fly-wheel delicately poised, which some slight agitation will cause to tremble and quiver. The weight of the earth as it revolves is constantly shifting. The pull of the sun and moon not only creates the ocean tides, thus transferring enormous masses of water from one place to another on the earth's surface, but it actually causes a tidal rise and fall in the solid crust. A heavy fall of rain or snow may cause hundreds of millions of tons to be suddenly applied in an affected area. This constant alteration in the distribution of the weight of the earth's surface tends to unbalance the delicately poised and fluidifiable barysphere with the result that tremors and earthquakes are felt upon the more rigid lithospheric crust.

Between the erosive and weight-shifting action of the hydrosphere and atmosphere from above and the lifting and depressing activity of the barysphere from below, the solid lithospheric crust is kept from enjoying a peaceful old age. Its troubles seem never to be over.

With respect to the origin and meaning of volcanoes,

it has long been known that they occur along the shore-lines of oceans and seas, and it was for a time believed that the action of water had something to do with their formation. Water, it is true, is associated with volcanic eruption, as in the clouds of hot steam that belch forth with other material; but the origin of volcanoes is another matter. Take an old air-filled rubber ball, like a tennis-ball with its outer covering removed, which has become soft enough for finger pressure to produce a considerable depression on its surface. If the rubber has become somewhat rotted, cracks will appear along the edges of the depression, and here and there the rubber may break allowing the inclosed air to escape. Now regard the ocean beds as giant depressions made on the earth's surface, by a cause to be explained presently, and regard the edges of these depressions as containing cracked and broken places. Through these cracks the fluidifiable barysphere pushes superheated material toward the surface, as it expands, or as some sudden earth movement, such as a further subsidence of an ocean bed, brings pressure to bear on these weakened coastal areas. Such is the currently held explanation of the origin of volcanoes.

After a time, through repeated eruptive activity, volcanoes acquire typical craters and mounds, but originally there was doubtless merely a crack or vent deep enough to reach the superheated material underneath and allow it to be pushed upward. The barysphere has been designated as "fluidifiable," which signifies that it is viscous and movable; the pressure of the earth's surface prevents it from actually becoming molten. But in rising through a vent, the pressure is reduced, the fluidifiable material fuses, and the typical eruptive activity of molten lava and steam takes place. Geysers are nothing more nor less than water-

volcanoes, the lithospheric fissure connecting with a superheated underground body of water instead of with fluidifiable metal.

By this time a question will undoubtedly have been raised in the mind of the reader as to why there are on the earth's surface giant depressions, such as ocean basins, and continental expanses of raised areas. If the barysphere is completely fluidifiable, does it not exert the same pressure in all directions upon the crust of the earth and thus tend to push it up equally at all points? For a long time this remained a puzzling question for geologists, especially after Dana had launched his noted theory of mountain origins. The twentieth-century answer falls into two parts, the first having to do with the rigidity of the lithosphere and the alternative expansion and contraction of the barysphere, the second focusing attention upon the densities of different parts of the earth's surface.

The earth's crust is very rigid compared with its interior. When the fluidifiable earth-core is contracting or expanding, wide sections of the inflexible surface must sag downward or fold upward. But these facts hardly explain the evident tendency for some gigantic areas to remain more or less permanently raised and others depressed. The most important part of the answer to the question raised above is the illuminating suggestion that various portions of the earth's surface are of differing densities, the continents being composed of much lighter material than the ocean floors, each large mass—regardless of how high it rises above the surface of the underlying fluid barysphere—pressing with equal weight upon it. The principle that the level of different parts of the earth's crust is determined by their weights has been called "isostasy." The lithosphere is said to rest in isostatic equilibrium upon the barysphere.

The theory of isostasy has recently been subjected to a

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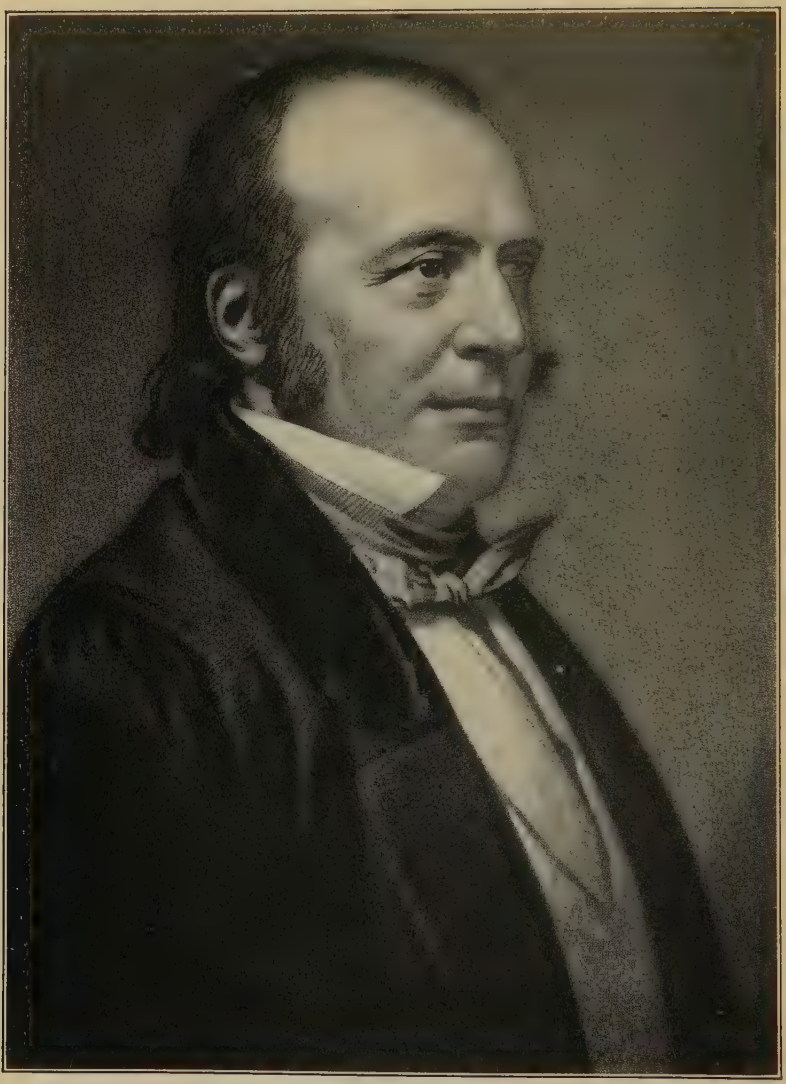


AGASSIZ

series of thorough tests, one applied to the bottoms of the sea and another to the surface of the United States. It has been strikingly borne out in these experiments, which indicate that the materials composing ocean bottoms are very dense, that those of the American continent are much less compact, and that great mountain elevations have the lightest of materials beneath them. The following is a statement by J. F. Hayford, the geologist who made the isostatic surveys of the North American continent: "The United States is not maintained in its position above sea-level by the rigidity of the earth, but is, in the main, buoyed up, floated, because it is composed of material of deficient density."

Epitomizing what is known of modern geology, we may say that the seal which hid its mysteries—the fifth Seal of Science—was broken between the third and fifth decades of the nineteenth century; that since then many previously obscure earth facts have become clarified; that the nebular hypothesis is now but a part of the broader principle of uniformitarianism which teaches that the geological processes at work to-day are quite the same as they have been throughout geologic time; that little change in mean temperature or atmosphere from earliest antiquity to the present is in evidence; that the earth is now thought of as composed of four main layers—a metallic core or barysphere, the rocky surface crust or lithosphere, the liquid hydrosphere, and the gaseous atmosphere—which rest in isostatic equilibrium one on the other and thus maintain, because of their respective densities, continental elevations and ocean floor depressions, but which are nevertheless in a constant condition of interaction, crumpling the earth's surface into mountains and valleys, occasioning volcanic upheavals, and through erosive activity sculpturing the earth's surface into the topographical features familiar to all of us;

and that the age of the earth is something like one thousand million years—a far cry from the misconceptions of a century back. The igneous formations and the fossilized strata of the sedimentary rocks tell a story that is clear and unmistakable. It can now be read by any one who will make the effort.

CHAPTER XII

MODERN BIOLOGY

§ 1

BIOLOGY is the science of plant and animal life as it has existed and as it continues to exist on earth. Since life did not emerge until atmospheric and other terrestrial conditions had become favorable, geological history goes back considerably further than biological; but for almost countless ages now, as has already become apparent, the animate and inanimate worlds have been developing in close relationship.

There is to-day a widespread belief that biology began as a science with the Hellenes. It is true that Aristotle and other Greeks stimulated research and made important contributions in the field of nature study, but to say that biology was raised to a scientific plane during their day is quite another matter. As a descriptive and speculative venture of the human intellect, observation upon plants and animals dates from earliest antiquity. Man has for an exceedingly long time, it appears, been curious about the structure and functions of his body, about the domesticated animals he uses for companions, drudges, and food, about the beasts of the forest, the birds of the air, and the denizens of the deep, about the multitudinous variety of herbs, shrubs, and trees, and the fruits of his agricultural labors. These things are nearer to him and arouse more interest in him than does the dead world of inorganic forms. But biology came of age no earlier than did geology; in fact, it lagged behind its sister science by a decade or so. It is to the days of Darwin

rather than to those of Aristotle that we must look for the final maturing of biology into a science. Before 1860 she was still enjoying her long period of adolescence.

This is, after all, as it should be. Our observations in the last chapter about the foundations of modern geology apply with equal force to biology. Both depend intimately upon the physical sciences, and in addition biology depends in part upon geology. Until the proper tools had been devised and the fundamental laws of physics, chemistry, and astronomy had been enunciated, naturalists could do little more than make superficial observations, and most of these observations were infused with prejudice and misconception. And until misunderstandings regarding the earth's age and sedimentary fossil relics were cleared away in geology, her sister science was still further hampered.

The history of the earth's life that is gone is written in the fossil remains. Here the stratigraphic department of geology and the paleontological department of biology combine to tell a story of fascinating interest. In the one, the study of fossiliferous strata brings to light the various ages through which the earth has passed in its development; in the other, the bearing of fossils upon the origin and evolution of living organisms is determined. Together they provide an excellent perspective from which recent biological advance can be the more intelligently appraised.

Present-day stratigraphy and paleontology separate the evolution of the earth into five vast eras subdivided into a dozen or more periods. The eras are designated the Azoic, Eozoic, Paleozoic, Mesozoic, and Cenozoic, the first three being more or less equal in length (from two hundred and fifty to three hundred million years, let us say), the fourth about half as long, and the fifth about one sixth.

The Azoic is the earliest era, during which there were probably no animals or plants on earth. For the vast reaches

of its duration, our planet, it appears, spun lifeless through space, for in its strata no fossiliferous remains of any description have been found. The Eozoic is so called because it represents the dawn of life on earth. During its periods no hard-bodied animals could have existed, for its sedimentary rocks show no trace of the fossil skeletons found later. The earliest animals were apparently devoid of bony structures. They were soft-bodied as, for example, earthworms are. The only evidence we possess of life during this second era is indirect, consisting as it does in the existence of sheets of limestone, graphite, and bitumen, which seem to have been formed by animal and plant activity. To account for this lack of bony structure during primordial time, a number of theories have been advanced, the most plausible explaining it in terms of a deficiency of carbonate of lime in the sea. This substance is necessary for the production of skeletons and hard shells, and the assumption is that it was only gradually formed in the ocean water until present in sufficient abundance to serve the needs of higher forms of organic existence.

The third era, the Paleozoic, is sharply differentiated from the second in that in its lowest strata of sedimentary rocks are already found the remains of many highly specialized forms of animals, such as species of corals, starfish, and numerous kinds of shell-fish. Later during this period, also called the Fish Era, many forms of sea-animals, of amphibians, such as our present-day frogs and toads, and finally of primitive reptiles, made their appearance. With the exception of the higher types of backboned land-animals, the Paleozoic or Fish Era contains specimens of the chief groups of the animal kingdom.

The next era, the Mesozoic, is the Era of Reptiles. It is distinguished from the preceding one by the disappearance from its strata of the fossil relics of many primitive

forms of animals and plants. Those that remain are greatly changed and more highly specialized. During its sway the last remaining types of higher animals and plants, such as mammals, birds, and flowering vegetation, made their appearance. The preceding era had been one of earthquakes, mountain formation, and widespread volcanic activity. The Mesozoic or Reptile Era indicates a marked change in this respect, for the earth settled down to a long repose, covering a vast stretch of slow, peaceful geographic development. During its extent gigantic reptiles dwelt in the sea, roamed the continents, and were supreme in the air. It was during this period that the great chalk beds of the British Isles were formed from the fossil remains of microscopic marine organisms in areas which were then under the sea. The era ended with another great volcanic outburst; immense sheets of lava were poured forth upon Africa, North America, and India, and vast lithospheric upheavals raised the ocean bottom containing a chalk bed of nearly a thousand feet in thickness into the gray-white cliffs of England, entitling that land to the name of Albion.

The Cenozoic or Mammal Era is the one in which we live. It was ushered in, as has just been indicated, by one of the most extensive volcanic storms in geological history. For some reason not yet clearly understood, the giant reptiles of land, sea, and air disappeared. Mammals and birds came into the ascendancy. All the great mountain chains known to-day, in Europe, Africa, Asia, and North and South America, were formed. In this era, also, the great glacial advances and retreats occurred, ignorance of which for so long a time created difficulties for geologists until the days of Agassiz. The "upheavals," "advances," and "retreats" here referred to must not be thought of in terms of sudden movement. They developed almost imperceptibly and were in process over relatively long periods.

Out of the fifty million years allotted by one prominent group of geologists for the duration of the Mammal Era (on the basis of an allowance of one thousand million years for the total age of the earth), man's existence accounts for five hundred thousand years, or one hundredth part. This most recent era is broken up into five periods, the Eocene, Oligocene, Miocene, Pliocene, and Pleistocene. No *Homo sapiens,* it appears, inhabited the earth before the Miocene Period—the age of the anthropoid apes. In the Miocene, definite human traces begin; they extend through the Pliocene, though no skeletal remains have yet been found dating back further than the Pleistocene (about one hundred thousand years ago on the very conservative time scale that is used here). To the beginnings of this last period, recently located human skulls and parts of skulls are attributed. The now famous Java (*Pithecanthropus*), Piltdown (*Eoanthropus*), Heidelberg (ancestor of Neanderthal), and Rhodesian men doubtless lived at about that time. It had taken their ancestors some four hundred thousand years, on the same basis of reckoning, to escape from the jungle bondage of the anthropoid to the freer life of "incipient manhood." Yet, even then, man existed in the lowest form of savagery. He had still to pass through the stone and bronze disciplines to the age of iron and the discovery of the art of agriculture, which mark the rise of the first civilizations in Egypt and Babylonia only about fifteen thousand years ago as compared with the vast reaches of time that preceded. Before these earliest civilizations, says Sir Arthur Keith, there was "neither house, barn, nor tilled field, only a wilderness pierced and fretted by paths along which hunters passed in pursuit of game." As Dr. Ales Hrdlicka expresses it, "Man's progress, his evolution, were hard earned and every step was paid for to the full."

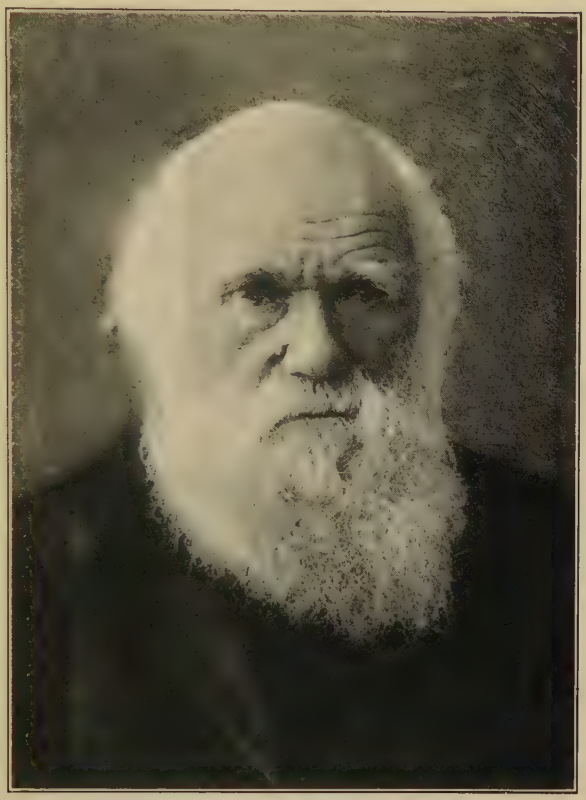
Let us assume for a moment, to throw these various

reaches of time into a quick perspective, that the total age of the earth is measured as ten thousand years. A year would then, on the basis of the figures given above, represent one hundred millennia of terrestrial development. On this shortened scale, ninety-five hundred years would elapse before the beginning of the Mammal or Cenozoic Era. Another 495 would have to be written off before human beings appear, and still another four to the reign of the Java, Piltdown, Heidelberg, and Rhodesian men. Only one year remains from the beginning of the Pleistocene Period to the present—one year out of ten thousand. Eight weeks ago Egypt and Babylonia were born; Greece was in swaddling-clothes a fortnight back; and hardly more than thirty-six hours have elapsed since Columbus sailed westward to discover America. Modern civilization is indeed young as measured in terms of geologic and biologic time.

§ 2

At the beginning of the nineteenth century the facts indicated in the preceding outline of the development of terrestrial life were, of course, unknown. In the biology as in the geology of that day, preconceived notions regarding catastrophes, special creations, and the age of the earth held the field, and a considerable amount of fact gathering based upon specialized microscopic and chemical methods of investigation had to intervene before an accurate and unbiased comprehension of organic development became possible.

There are, after all, very few outstanding figures in biology until comparatively recent times. Aristotle and Theophrastus among the earlier Greeks; Dioscorides and Galen among the later ones; then a lapse of some thirteen or fourteen centuries before Cordus in botany, Vesalius in animal anatomy, and Harvey in animal physiology defied



CHARLES DARWIN

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medievalism and reëmphasized the necessity of first-hand observations. With the scientific renaissance of the seventeenth century, the investigations of microscopists such as Swammerdam and Leeuwenhoek and the brilliant researches of Redi, Steno, and Malpighi clearly demonstrated that biology had no more than scratched the surface of the facts it must penetrate and understand before it could begin to form scientific generalizations. The accomplishments of a dozen men sum up this preliminary spadework. Improved microscopic technique, the enunciation of fundamental physical laws, and the rise of the science of chemistry were still ahead.

With the eighteenth century, biological progress became accelerated to some extent. Linnæus invented a system of taxonomy which, though artificial and based upon an erroneous hypothesis concerning species, was somewhat helpful for the furtherance of intelligent fact gathering. General anatomy—as distinguished from comparative anatomy and histology (microscopic study of tissues), which are nineteenth-century products—had already been established, but general physiology and embryology were still in their infancy. It was during this century that Hales worked out the mechanics of plant nutrition and Saussure its chemistry; that Haller started a movement in animal physiology which ultimately led to a clear understanding of the physics and chemistry of respiration and digestion; that Wolff came to grips with Haller over the rival embryological theories of preformation and epigenesis and laid the basis for the highly significant developments which came later; and that Buffon and Erasmus Darwin gave color to the evolutionary hypothesis, although the opposition was still so overwhelming and the substantiating facts so few that the period ended with the theory in almost complete eclipse.

At the beginning of the nineteenth century, the catastrophic-change and special-creation misconceptions were hampering progress in biology in the same way that they were in geology. In the one field, they prevented the establishment of proper theories regarding the development of animals and plants, just as in the other they hindered the acceptance of scientific hypotheses regarding the origin and age of the earth and the sculpturing of its topographical features. The discrediting of these false ideas in geology helped break the way for discrediting them in biology, a much more difficult task because of the depth of the prejudice. In geology the first real clash between misconception and scientific hypothesis came toward the close of the eighteenth century (1795), ending in the temporary victory of preconceived notions. An analogous situation arose in the field of biology a decade and a half later (1809)—if we disregard the preliminary skirmishes of Buffon and Erasmus Darwin—and again prejudice remained in the saddle. In the one instance it was Werner versus Hutton; in the other it was Cuvier versus Lamarck. In the one field, a generation elapsed before Lyell (1830) renewed the conflict and broke the hold of the Wernerians. In the other field, it took half a century before the man and the hour came for a similar triumph (in 1859). In these struggles, it became clearly evident that, where deeply rooted prejudices are concerned, a few facts, no matter how conclusive they may appear to one or two far-sighted pioneers, are not enough to carry general conviction. Under such circumstances the evidence must become overwhelming before progress is assured.

Among early nineteenth-century naturalists, Lamarck and Cuvier stand forth conspicuously. The mature views of these two eminent Frenchmen are in sharp contrast, despite similar influences and training. Both were designated by

their parents for the ministry, from which they turned aside in favor of natural history. Both had an orthodox religious rearing, but the one in the end broke through the dogmas of his day and heralded the coming of a truer belief, whereas the other allowed the dogmas to dominate his thinking and by virtue of his superior influence helped to retard progress in a most important direction for half a century.

Jean Baptiste de Lamarck (1744-1827) forsook his clerical preparation at the age of sixteen to enter the army, where he distinguished himself; but he was soon forced to retire because of physical disability. He then took up the study of medicine and became interested in botany, in which field he published a noteworthy book as early as 1778, at the age of thirty-four. This publication resulted in his election to the French Academy of Sciences and later in his appointment as royal botanist, in which position he traveled through Holland, Germany, Hungary, and other countries studying public and private botanical collections. Upon his return he was, in 1783, appointed keeper of what after the French Revolution became the famous Jardin des Plantes at Paris. In his ten years' service at this institution he did much to raise it to the high esteem in which it has since been held. In 1794 he entered upon a post in another biological field, in that of invertebrate zoölogy, at the Museum of Natural History. Here he did his most important work, leading finally to the publication of his justly notable "Natural History of the Invertebrates." It is in this book, published between 1815 and 1822, that his evolutionary theory is enunciated.

Lamarck made evolution much more than a speculative suggestion, as it had largely been with Buffon and Erasmus Darwin. He worked it out in considerable detail and supported it with many pertinent facts. His investigations were

followed up vigorously by a small group of evolutionists in Paris, who issued a number of pamphlets on the subject, much to the disgust of Cuvier, who hailed each issue as a "new folly."

Baron Georges de Cuvier (1769-1832) was younger than Lamarck by twenty-five years. He also forsook his theological studies very early and pursued work in natural history. During a period when he was employed as tutor in a nobleman's family on the coast of Normandy, he seized the opportunity to make a study of marine life and fossils. After his ability had been brought to the attention of Lamarck and others in Paris, he was called to the Museum of Natural History in 1795 as assistant in the field of comparative anatomy. From this point his rise was rapid. In 1802 he was placed in charge of the Jardin des Plantes and was appointed to high political office in the field of education. With Napoleon as emperor, his public position became still more important. He was a counselor of state when the Corsican fell. Afterward he became successively president of the Committee of the Interior, chancellor of the University of Paris, grand master of the Faculties of Protestant Theology, a grand officer of the Legion of Honor, and finally, in 1832, the year of his death, he was made a peer of the realm by the new king. In a land predominantly Catholic, the brilliant career of this notable Protestant stands forth all the more strikingly.

Cuvier had been brought up very strictly in the Calvinistic belief, to which he unquestioningly adhered throughout his career. It was natural, therefore, though not in keeping with his otherwise keen intelligence, that when Lamarck advanced the idea that all life is derived from a "primitive common stock, with man at the head of the order of primates," Cuvier should on behalf of the book of Genesis impatiently take up the challenge and denounce his con-

temporary's views as sheer nonsense. It was Cuvier's uncompromising stand and influential position which caused Lamarck's evolutionary contentions to fall, in the main, on deaf ears. Besides his opposition to the idea of gradual development, Cuvier emphasized the dogma of catastrophism in geology, held fast to the preformation theory, and believed in the spontaneous origin of complex organisms such as flies or snakes—all of which have since his day been completely discredited.

Had Cuvier's scientific activity consisted solely in opposing the evolutionary ideas of Lamarck and in holding fast to prejudicial theories, his name might be remembered as a churchman and educator but not as a scientist. That his name has not passed into oblivion among men of science is because of the many solid contributions he actually made, contributions which, in fact, ranked him as the outstanding biological authority of his day. Three notable books established his reputation. One, published in five volumes from 1800 to 1803, is a systematic study of comparative anatomy in the animal world, covering both vertebrates and invertebrates. Another important book, on fossil bones found near Paris, came out in 1812. The third, which appeared four years later, attempted an improved classification of the animal kingdom, and is a decided step in advance of the taxonomy of Linnæus, though not abreast of that suggested by Lamarck.

Both Cuvier and Lamarck improved upon the Linnæan classification. In keeping with the idea of inseparable chasms between species, there had developed with Linnæus the *scala naturæ,* which supported the claim that animals, considering the entire field, form a graduated linear series, with no divergences, by-paths, or overlappings. A straight line would represent the scale of nature, each animal species occupying its appropriate position on the line. Lamarck at

first accepted this theory of classification, but by 1809 he had discarded it entirely and had substituted a genealogical tree in which the divergent branches were made to represent the relationship between animal species. Such a system, though crudely conceived by Lamarck, is quite in keeping with modern ideas. It was not taken seriously in his day, however, because it was bound up with his evolutionary hypothesis.

Cuvier was from the first also opposed to the scheme of the scale of nature, though on different grounds from those of Lamarck. In his studies he had compared and correlated parts of one animal species with those of others and had noticed that on the basis of structural similarities there is much overlapping. So long, in fact, as general description rather than comparison of structural details remained the key-note of classification, a scientific basis was impossible. And the scale of nature was wholly descriptive. Cuvier's penetrating analysis completely overthrew the Linnæan scheme and marked a turning-point in taxonomic advance.

With respect to the field of paleontology, Cuvier helped drive the final nail into the coffin of medieval ideas regarding the nature of fossil remains. Being called upon to examine the peculiar bones unearthed in certain quarries near Paris, he recognized them at once as belonging to animal species no longer existing on earth. For a quarter of a century he collected and analyzed such fossils, and his 1812 publication was the result of these researches. His wide knowledge of living species, and his ability to construct an organism from whatever parts might be available, made it clear to him that many fossil relics belong to animals now extinct. Cuvier's labors in this field were of the highest importance, even though he held fast to the idea that widespread catastrophes and floods cleared the earth of all living organisms from time to time and that the Creator

restocked it out of hand with new forms after each catastrophe.

What Cuvier did for vertebrate paleontology, Lamarck did for the invertebrate realm. Through Lamarck's collection of shells and similar fossil remains, an array of evidence was brought together which, coupled with Cuvier's researches on the fossils of higher animals, laid firm the foundations for the biological sub-science of paleontology. But Lamarck's conclusions were opposite to those of Cuvier. He saw in the relics gradual transformations and a continuous process of growth from one species to another. And, although his ideas suffered temporary eclipse, we now know that he was right and that Cuvier was wrong. All in all, Lamarck is one of the outstanding geniuses of science, but his high rank was not recognized until recently.

Cuvier's chief contribution to biology lay in establishing the principle of correlation, which he applied in all the fields he advanced. "Give me a tooth," he said, "and I will construct the whole animal." He demonstrated, for example, that the cleft hoof, certain kinds of teeth, and a ruminant's stomach invariably go together, and that sharp claws, cutting teeth, and a special form of alimentary tube are likewise always associated. He grasped the comparative anatomy of the whole series of animal forms, living as well as extinct, and his principle of correlation soon reflected itself in developments elsewhere, especially in physiology and embryology.

§ 3

In physiology, the meaning of circulation, respiration, and digestion—the three major functional processes in biology—had been made clear by the beginning of the nineteenth century. It was in this field, as the application of chemistry to vital processes came to be understood, that a

number of prominent biochemists did such excellent work as the period got under way. After the middle of the century the versatile German biologist Johannes Müller (1801-1858) utilized Cuvier's principle of correlation to establish the sub-science of comparative physiology. Müller had a wide influence as a teacher and investigator and was regarded as the leading physiologist of his time. He had a wonderfully magnetic personality and did a prodigious amount of work, all of the highest quality. His investigations into the physiology of the brain are especially notable, and it was under his leadership that serious research into psychophysiological subjects was begun. Both in comparative physiology and in psychobiology, the emphasis is still where Müller and his disciples placed it. In embryology, which traces the growth of the organism from impregnation to birth, comparative studies began with another outstanding genius, the great Baer. The application of the correlation principle to the major departments of biology forms one of the most important biological accomplishments of the nineteenth century. In establishing it, Cuvier well deserves a place among the great men of science.

§ 4

The contributions of Karl Ernst von Baer (1792-1876), a native of Esthonia, were also of importance. It was he, in fact, who formulated the first of the three great generalizations which ultimately, after the middle of the nineteenth century, swept aside medieval preconceptions and placed biology upon a sure scientific basis.

The greatest work on embryology to this day is Baer's "Development of Animals," the first part published in 1828, the rest shortly afterward. The value of this monumental treatise might be discussed from a number of angles, including its detailed application of Cuvier's correlation

principle to the field of embryology; but its most notable achievement lay in the establishment of the germ-layer theory, which holds that the many specialized parts of the adult organism, such as the nervous system, the alimentary canal, and the body wall, develop from embryonic leaf-like layers, four in number (reduced by later investigators to three), which are identical in all the higher animals. Through his exhaustive comparative studies, Baer determined the chief stages of embryonal development to be as follows: first the fertilized egg and its differentiation, then the germ-layers, and finally the specialized tissues and organs. This sequence of development was tested by Baer's followers and found to apply throughout the whole animal kingdom.

A moment's reflection will indicate why Baer's law, as it is now known, is so important. By reducing the many complicated tissues and organs of animals to several identical embryonic germ-layers, a significant step was taken toward finding the fundamental elements out of which all specialized organic structures are produced. Baer's law is for this reason regarded as the first great generalization of scientific biology. It reconciled in part the epigenesis and preformation theories over which Haller and Wolff had contended, and followed Wolff's work and that of his disciples to a successful outcome.

Almost immediately after the establishment of the germ-layer hypothesis came the enunciation of the cell theory, which, with the later discovery of protoplasm, constitutes the second great generalization of scientific biology. Wolff's pioneer work had also furnished the clue to this important development. His discovery that in the early stages of an organism's growth there appears "a little mass of clear, viscous, nutritive fluid," out of which not only animal but also vegetable tissues and structures are organized, pointed

to a truth of even more fundamental significance than the germ-layers. Yet the discovery of just what this truth implies was not made by embryologists but by anatomists, or rather by specialists in that department of anatomy which emphasizes microscopic technique and which is designated as histology.

It has been pointed out that general anatomy deals with the structural or architectural phases of biological study. It considers how the bricks and mortar of the complete organic edifice are put together, though it does not examine their composition as such, this more detailed study being comprehended by the special anatomical department of histology. Aristotle had classified the component parts of the adult animal into unorganized substance, homogeneous tissues, and heterogeneous organs. There the matter had rested until the eighteenth century, despite the extensive observations of the microscopists a hundred years before and the suggestion of Hooke that cork tissue under the microscope looks like "little boxes or cells."

The pioneer in modern histological research was a French genius by the name of Bichat (1771-1801), whose life was cut short in his thirty-first year by a fatal accident, but who, nevertheless, in his brief career—he was appointed professor of anatomy at the University of Paris at the age of twenty-six—published three books, all of them worthy of a high place in the literature of science. Bichat made a penetrating study of adult animal tissues, indicating the importance of the subject; and his followers developed the microscopic technique so universally utilized in the field to-day. Through their efforts it came to be realized that Aristotle's division of the bricks and mortar of the mature body into substance, tissue, and organs might be further reduced. During the first third of the nineteenth century the microscopic examination of biological structures took

on wide scope and resulted in a great quantity of additional information. That there are such things as plant and animal cells now came to be generally accepted, but little importance was as yet attached to them, even with the discovery by an English biologist (Robert Brown) in 1831 that plant cells contain a nucleus, which he maintained had something to do with their growth.

So much for the antecedents of the cell theory. Its enunciation finally came in 1838-1839 as the result of the labors of two friends, Schleiden (1804-1881) and Schwann (1810-1882). Schleiden, who was both lawyer and physician, had become impressed with the necessity of understanding more clearly the organization of plant fibers. He devoted himself to botanical studies, forsaking the practice of his professions, while his friend Schwann, then a laboratory assistant at the University of Berlin, investigated animal forms. Comparing their results one day after dining together, they were struck with the identical character of the structure of plant and animal tissues, and this led to the formulation of their theory. Schwann, who had obtained his inspiration and training under the great Müller, was more profound and thorough than his friend, as his comprehensive treatise published in 1839 demonstrates. This book, his famous "Microscopical Researches," is, like Baer's, a landmark in biology and a masterpiece of comprehensive research. Its author states his theory thus: "The development of the proposition that there exists one general principle for the formation of all organic productions, and that this principle is the formation of cells, as well as the conclusions which may be drawn from this proposition, may be comprised under the term cell-theory."

The essence of the hypothesis is that the various specialized animal and plant parts found in the adult organism are all composed of elements more or less identical in

structure. This generalization has been thoroughly substantiated. But the form in which it was launched by its two founders was somewhat imperfect with respect to the exact nature of the elemental cell and the manner of its development. The difficulties here were cleared up with the discovery of protoplasm.

A number of biologists from the time of Wolff had noticed the semi-fluid jelly-like substance associated with organic activity. It had been variously designated as viscous fluid, sarcode, gum, and finally, by Mohl, as protoplasm. By 1850 it had been definitely asserted (by Cohn) that this substance is the basis of all living matter, but it was not until Max Schultze (1825-1874) in 1861 published the results of his extended investigations that its significance became recognized and the cell theory took on its modern aspect. It then became clear, not only that animals and plants are anatomically aggregations of cells, but also that each cell is composed of protoplasm with its embedded nucleus.

The original cell out of which each higher organism grows is the fertilized egg or seed. This develops by a process of division and multiplication (repeated splitting in half as it grows) until the germ-layers appear, and these in turn unfold into the tissues, organs, and other parts of the full-grown organism, each adult part being still made up of protoplasmic cells. With the establishment of Baer's germ-layers from 1828 to 1837, and of protoplasm and the cell theory by Schleiden, Schwann, and Schultze from 1838 to 1861, two of the three cornerstones of scientific biology had been securely laid. It is to be noted that these important discoveries came only after the perfection of microscopic technique and chemical methods for preparing and staining organic specimens had enabled biologists to reach down and

interpret aright the fundamentals out of which a scientific understanding of their subject had come.

The third foundation-stone of scientific biology, as is now well understood, is the doctrine of organic evolution, clearly enunciated by Lamarck but not accepted until an overwhelming array of substantiating facts had been presented to combat the deeply rooted prejudices against it. Part and parcel of this marshaling of facts were the studies in comparative histology and embryology which have just been reviewed. The evolutionary theory was not in acceptable form until these researches and certain others, now to be examined, were completed. The final triumph came with the publication of Charles Darwin's monumental work, "The Origin of Species," in 1859.

Charles Darwin (1809-1882), grandson of Erasmus Darwin, was born in England and received an early medical training at Edinburgh, later going to Cambridge, where he took a baccalaureate degree in 1831. During this period he showed no particular genius for biology and was quite undecided about his career when he graduated. Immediately afterward, however, an event occurred which settled his life's work for him. This occurrence was his appointment to the post of naturalist on the *Beagle,* a ship which was setting out on a five-year, round-the-world surveying tour. Darwin went on the voyage, which through his labors has become historic, collected a voluminous amount of biological specimens on various islands and coasts, especially in South America, made extensive notes regarding the fossil remains and living forms he had observed, and after his return spent the following twenty-two years in studying, classifying, and writing up his observations before his "Origin of Species" appeared. Nor was this his only important biological publication. Another twelve years of re-

search, observation, and correspondence with contemporary naturalists followed the first twenty-two. All in all, ten noteworthy books are the products of Darwin's colossal perseverance, industry, and genius; an achievement all the more remarkable in the light of the fact that after his *Beagle* voyage, he knew hardly a day of good health. A severe digestive disturbance, accompanied by dizziness and weakness, pursued him for the rest of his life. Aside from "The Origin of Species," Darwin's "Descent of Man," published in 1871, is the most important of his publications. In it the doctrine is put forth that man, like other animals, is a part of the evolutionary process and that not only his body but his mind is subject to the same universal tendency —a doctrine which of late has had a revolutionary effect in the field of psychology.

Let us now for a moment consider the question: what is evolution and on what grounds is it held to-day? Very broadly conceived, this hypothesis may be applied to the whole gamut of existence, astronomical, geological, biological, and psychological, to portray the unfoldment of the present complex universe from simpler forms. Evolution thus understood represents "the unrolling of the scroll of the universe" and is thought to have proceeded, in Herbert Spencer's well known phrase, from homogeneity to heterogeneity, although recent investigation casts some doubt on the complete accuracy of this generalization. More narrowly applied, evolution pertains to organic development only, to the conception that the present complex forms of life have been derived from simpler antecedents. Organic evolution states most emphatically that species are not fixed and unchangeable and were not created in one sudden stroke, but that they have varied considerably and that the forms now existing have slowly developed from more primitive ancestors.

The facts, so relentlessly marshaled by Darwin, upon which evolution in this restricted sense rests, are not difficult to understand. To begin with, organic development is wholly a historical question. A comprehensive knowledge of the history of plant and animal life is necessary to settle it. Stratigraphy and paleontology are here of supreme importance. The story of past life on earth, preserved in the fossil remains embedded in stratified rocks, has been traced back, as we have observed, hundreds of millions of years. Snails, for example, inhabiting certain fresh-water lakes through countless generations, have left their petrified remains behind them, layer on layer in the clay and mud of the bottom—"held there like currants in a pudding." Where this bottom has through the ages hardened into rock, the evidence of the history of the snail's development is preserved in chronological order, the latest forms at the top, the earliest in the bottom strata. A collection of such shell remains, arranged in proper sequence, should demonstrate whether a species dwelling through many ages in one spot has as a matter of fact remained immutable. In several noteworthy collections of this character a definite transformation over thousands of years is clearly indicated.

It is possible to tell a similar story for the higher animals. The remains of the horse, to take another example, are found preserved in the rocks of the western United States, in strata representing a period of some five million years. This friend of man apparently began its career in North America and from there migrated to other parts of the globe. An extremely interesting collection at Yale University depicts thirty stages in its history, shows it to have evolved from a four or five-toed ancestor about the size of a fox, demonstrates the changes in toes from four to three and to two and finally to one, and indicates many addi-

tional transformations, including a gradual increase in size. Other collections of fossil remains tell the same story, until we are now in a position to divide the history of past life on earth into the vast eras depicted at the beginning of this chapter. In the earliest period only invertebrates were inhabiting the globe; then fish with bony skeletons appeared; then amphibians, reptiles, and birds; and finally, the most complex forms of animals, ending in the mammals and the primates of which man is the highest expression. Such is the story told by fossiliferous strata.

Besides the record of the rocks, there are many additional forms of evidence bearing on organic evolution. Embryology furnishes interesting testimony. As the animal passes from the embryo to the fully formed creature it seems to recapitulate the history of life on earth. Gill-pouches appear and pass away; other rudimentary fish organs come and go; and, as the embryo develops further, various vestigial structures either appear for a time and then disappear, or become a permanent part of the organism though serving no useful purpose. In the human body, 180 rudimentary structures have now been recognized as indicative of an evolutionary relationship of man to lower animals. Among these strange traces may be mentioned the strong grasp in the fingers of the new-born infant (with a power which soon passes away), the vestigial tail, and the rudimentary muscles of the ear, which are sometimes consciously controllable, as in the growing boy who amuses his playmates with his antics and scandalizes his parents. The discovery of prehistoric human fossil relics, linking man with a lower primate still only vaguely known, furnishes another form of evidence to strengthen the evolutionary hypothesis. The story told by the sedimentary rocks, the recapitulation of earlier forms shown in the growth of the embryo, the innumerable analogies observed in compara-

tive studies, the fact that the germ layers, the cell, and protoplasm are virtually identical throughout the vast reaches of organic existence—all these witnesses combine in their overwhelming demonstration that organic evolution is a fact. What the *causal* elements are, is a matter still in dispute; but the *fact* of organic evolution is no longer open to question except by those who refuse to face the evidence.

Beyond organic evolution, unmistakable proof of mental evolution is also accumulating. It is now recognized that the degree of intelligence in animals depends intimately upon the structure and size of the brain and the complexity of the nervous system. The fine series of neural gradations between different animal species, brought out by comparative studies, leaves little doubt that the whole animal kingdom possesses intelligence, ranging from a very primitive form in lower organisms to the high type possessed by man. But this is another story from the one of organic development under consideration here.

With the publication of Darwin's epoch-making "Origin of Species" in 1859, in which the evidence for organic evolution was assembled in indisputable form, the third cornerstone of scientific biology was securely laid. Baer, Schleiden, Schwann, Schultze, and Darwin—these are the nineteenth-century master naturalists who broke the sixth Seal of Science. By 1861, when protoplasm as the basis of all living matter was finally recognized, biology had come of age and had taken her place alongside her sister geology in the family of the sciences.

§ 5

In the two thirds of a century since biology became established, exceedingly important advances have been made in further comparative and histological studies, in the rise of the new department of genetics, and in the analysis of the

causal elements behind evolution. Improved tools together with the three far-reaching generalizations just outlined have been the motivating factors. There has been other progress also, as in practical applications to medicine and surgery; but such developments, though important, are not a part of the main stream of biological advance and can only be touched upon incidentally here. If space permitted, however, an interesting account could be given of the rise of bacteriology, the biological sub-science which studies the peculiarities and propensities of bacteria and other micro-organisms, and in respect to which the names of Pasteur, Koch, and Lister have come to hold an enduring place as benefactors of the human race. The work of these men, furthermore, had a direct bearing on the much disputed doctrine of spontaneous generation which Redi in his experiments on flies' maggots had tried to disprove. Pasteur's researches laid the ghost of a spontaneous origin of complex organisms for all time. Bacteriology could, of course, never have arisen as a department of inquiry but for better forms of microscopes with unusual magnifying faculties.

The microscope is being steadily improved, with respect both to finer mechanical adjustment and to greater magnifying power. The invention of an ultra-microscope has recently been announced, with which it is hoped to watch the behavior of certain exceedingly minute micro-organisms, which thus far have defied observation, and which it is thought may be the cause of cancer, influenza, and other mysterious maladies. Other useful biological instruments have also been perfected, such as microtomes for cutting very thin sections of organic tissue for microscopic examination, and remarkable chemical staining devices by means of which, for example, the delicate fabric of the nervous system stands revealed.

In the fields of histological and comparative investiga-

tion, Bichat, Müller, and Baer have been followed by a large company of distinguished specialists. Histological research has of late taken on phenomenal dimensions, both normal and pathological tissues coming in for extensive study. Prominent among these researches have been the applications of microscopic technique to diseased structures (Virchow) and to a better understanding of the nervous system and the sense-organs (Ramón y Cajal). Müller left a tremendously inspiring legacy for comparative physiology at his untimely death in 1858. Here, again, the greatest recent advance, outside of the further application of physico-chemistry to the ordinary vital processes of the human body, has come in a better understanding of the sense-organs and the nervous system. Ingenious methods have been devised for testing the response of muscles and nerves to different forms of stimulation and for measuring the rate of flow of nerve currents. The influence of such studies upon the rise of psychology is one of the high spots of twentieth-century scientific advance.

The outstanding recent development in comparative biology, however, has come in the field of embryology, or rather as an outgrowth of it, for it is on the basis of Baer's findings that the new department of genetics has taken its rise. Genetics is to-day a field of major biological interest. It examines such important problems as the sources of new life and the laws of inheritance.

Upon the discovery that the embryonic germ-layers are the rudiments of the specialized tissues and organs of the mature body, and that the union of egg and sperm is the source of each new generation of plants and animals exclusive of the simplest types, attention of investigators became focused upon these germs of new life and especially upon the fertilized egg, its constitution, and its behavior. In examining the mature egg and sperm before fertilization,

it had been observed that they are single-celled, that they exist in a dormant state until their union, and that afterward the fertilized egg goes through a process of growth and development, quite similar in general outline to that exhibited by the lowest forms of organic life, such as the amœbæ, which are also single-celled. The latter grow to maturity and split into two parts, each half becoming the starting-point of a new organism, which in turn grows and divides, the process continuing more or less indefinitely. In higher forms of life, the adult does not itself split in two but delegates to egg and sperm the function of producing progeny. The union of these germinal elements starts a process of division and multiplication in the fertilized egg similar to that which is discernible in the amœba. This process seems uniform at the beginning, and many cohering cells with apparent identical constitution are produced. Then the germ-layers appear, and the cells composing them, though following the same mode of division, became specialized in their activity, producing the body wall here, the bones there, the vital organs elsewhere, and so on until the complete organism is manifest, as in the new-born child, in the newly hatched chick, or in the young plant-shoot pushing its way through the soil.

With the elucidation of these facts, the question of how the embryo matures had been answered with a fair degree of completeness. The focus of attention was now shifted from embryology to heredity. The egg and sperm, in addition to being the sources of new life in higher organisms, are evidently the conveyors of inherited characteristics, for they are the only substances that pass from one generation to the next. Two important avenues of approach have been found to the problems of inheritance: one, in the more minute examination of the germinal elements; the other, in experimental and statistical studies of offspring to deter-

mine how far and in what respect they resemble their parents and grandparents.

It was thought for a time that egg and sperm cells were simple and structureless in organization. But when it came to be realized that it is these germinal elements which after fertilization produce the germ layers and the various specialized body parts on the one hand, and such different ultimate results as a snake, a sparrow, or an elephant on the other (Baer maintained that he could not positively distinguish the embryo of a reptile, a bird, and a mammal at certain early stages), a more careful microscopic analysis, especially of the protoplasmic content of the fertilized egg and its nucleus, was undertaken. By 1875 it had been decided that the basis of hereditary qualities lies within the nucleus. Nine years later the important discovery was made that during cell-division tiny rod-like bodies make their appearance in the nucleus, their number being always the same for a given species of animal or plant, but dissimilar for different species. These rod-like bodies, designated chromosomes, range as a rule from two in number to twenty-four and apparently hold the key to the hereditary transmission of the traits which distinguish one organic species from others. Just as the number of electrons in the atom differentiates one element such as oxygen from another such as mercury, so the number and kinds of chromosomes in the nucleus of the fertilized egg differentiate the embryo man from the embryo snake, the embryo sparrow, or the embryo elephant.

This statement regarding a characteristic number of chromosomes to a species holds true not only for the fertilized egg in its first divisions but also for the adult body cells whether found in bone, skin, or vital organs. The only exception, curiously and yet significantly enough, lies in the *unfertilized* egg and sperm, which by an interesting process

are at an early stage deprived of half their chromosomes. Upon their union the distinctive number is again supplied and the change from dormancy to active growth takes place. What a fascinating story of natural law is here disclosed! The egg and sperm are indeed wonderfully constructed, and their activity after union is more wonderful still. We now recognize within the cell not only protoplasm and a nucleus, containing a distinctive number of chromosomes, but a "centrosome" just outside of the nucleus and a complicated surrounding "cytoplasm."

By the time the foregoing facts regarding the hereditary aspects of cell structure had become established, another question pertaining to inheritance had arisen, namely: How are the egg and sperm cells produced in the parent organism? Do the various mature body tissues and organs send small particles through the blood stream or otherwise to the ovaries, testes, and similar glands, where the germinal elements are created out of the aggregate of these particles, or are they produced in an entirely different way? Darwin put forth the suggestion, just outlined, that the egg and sperm are composed of minute substances derived from the body parts of the adult organism, a complete representation of the qualities of the parents being thus incorporated in the fertilized egg, which in its development carries these parental characteristics to the tissues and organs it builds up in the offspring. This hypothesis, called the theory of pangenesis, sounds reasonable enough. It has not been borne out in subsequent research, however, at least not in so far as the initial production of the germinal elements is concerned.

For a while the pangenesis theory was tacitly accepted. Then it came to be recognized that there is a separation or setting apart of germ cells from body cells at the very beginning of the fertilized egg's development, and that these

specialized cells mature and multiply without any apparent assistance from the rest of the organism. Careful microscopic studies have demonstrated that the germ cells do not mix with the body cells nor are they derived from them. The body cells house the germ cells, but otherwise the egg and sperm have an unbroken life of their own from generation to generation. Thus the child inherits its constitution not only from its two parents but from its four grandparents and its eight great-grandparents and so on back indefinitely. With this new conception of a continuous germinal life has also been linked the recapitulation theory and its explanation (in terms of retracing the ancestral history of the race) of the many rudimentary organs that appear in the course of embryonic development.

The principle of germinal continuity, suggested by various investigators from 1860 on, was finally established by August Weismann (1834-1914) in 1900 in his treatise entitled "The Germ Plasm." The doctrine is now regarded as one of the most important developments, if not the most important, of twentieth-century biology. Besides Weismann, the great names following Baer in the field of microscopic analysis of egg and sperm are Virchow and Balfour, the latter's tragic death at the age of thirty-one—in a fall from an Alpine height—taking away before his time a biologist of supreme promise, a man who had already in his brief span done notable work.

Two important considerations grew out of Weismann's doctrine, one having to do with the possibility or impossibility of transmitting to offspring characteristics acquired in any one lifetime, the other concerning the general laws of inheritance—how, in short, the parental, grandparental, and still earlier traits are actually apportioned in progeny. The first consideration has been categorically dismissed by Weismann and his followers, who maintain that, since the

children are descended not from the body cells but from the germ cells which live an unbroken life of their own, characteristics acquired by the individual are absolutely uninheritable. Other biologists, though agreeing with the premise, take issue with the conclusion on the score that changes in the organism may be communicated to the germ cells (which it houses) in some subtle way not yet discovered. The blood stream may be this communicating medium. The question is still in a highly controversial state. The second consideration opens up the other avenue of approach to an understanding of inheritance, namely, the experimental and statistical. The study of how hereditary traits are actually apportioned in offspring—whether sperm and egg characteristics are completely blended or variously mixed in fertilization—goes quite apparently beyond microscopic technique. Many mature specimens with a common line of ancestry must be observed and statistical averages prepared.

This second line of approach to the problem of heredity did not attract attention until recent years, although an Austrian monk by the name of Gregor Mendel (1822-1884) had as early as 1865 made a masterly statistical analysis based upon eight years' experimental study of twenty-two varieties of garden peas. His results lay hidden in an obscure journal till 1900, when they were unearthed and given the prominence they deserve.

Mendel's discovery of "dominant" characteristics which appear in the first generation, and of "recessives" which lie dormant till the second and always play a lesser part in inheritance than the dominants, has been applied to the animal as well as to the plant world and has been completely verified. The now well known Mendelian laws are of outstanding importance to an understanding of heredity. Supplemental to them is the law of ancestral inheritance formulated in 1889 by Francis Galton (1822-1911), a half-

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THE ANCESTOR OF THE HORSE

(the four-toed horse *eohippus,* as restored by C. R. Knight, American Museum of Natural History)

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cousin of Charles Darwin. This law states that " the parents together contribute one half the total heritage, the four grandparents together one fourth, the eight great-grandparents one sixteenth, and all the remainder of the ancestry one sixteenth." Although these numerical relationships have been slightly modified by further experimentation, Galton's law has in principle been substantiated also. The work of these two men furnishes the basis, in large part, for a scientific understanding of heredity. Parental qualities are not merged and blended in the fertilized egg but are mixed in varying degrees and retain their individualities in the offspring for an indefinite number of generations.

Genetics has indeed become an important branch of biological inquiry, to many specialists the most important. So far as social problems are concerned, there is certainly no phase of more vital significance. The mutually responsible part played by male and female in the production of new life, the unbroken line of germinal continuity extending back to the very beginning of organic existence, the mixing of hereditary characteristics in endless variation from generation to generation—these are facts too little appreciated as yet, especially by those self-styled reformers who through ignorance, sentimentalism, and prejudice attack the very measures (such as the sterilization of the unfit) which would unquestionably lessen the social ills—poverty, insanity, and crime—against which they so loudly inveigh.

Along with the establishment of the principles of genetics, has gone a lively discussion concerning the causal factors behind evolution. Lamarck and Darwin both contributed to this discussion, and so did Weismann. A fourth name should now be added, that of Hugo de Vries (1848—). These four men and their followers represent the best of biological thinking on this highly controversial question.

Some biologists assert that heredity tells the complete story of evolution's cause; others insist that environment is of even greater importance. Wiggam in his recent books stresses the one factor; Langdon-Davies emphasizes the other. To those who stand on the side-lines, the latter's tirade against Wiggam as a "heredity fiend" must sound very much like the pot calling the kettle black, for Langdon-Davies is nothing if not an environment enthusiast.

Both heredity and environment are undoubtedly important factors in the evolutionary process, but there is another factor which some biologists assert lies deeper than either of them. It is epitomized in the word "variation," and emphasizes the well known fact that although children are more or less like their parents or grandparents, they nevertheless show marked divergences.We say no two individuals are exactly alike despite heredity and environment. It is in this connection that Vries has made a notable contribution. In his experiments with plants he discovered sudden changes or mutations which breed true and give rise to new species. Wherever the truth will finally lie, it is well to bear in mind that, with respect to organic evolution, three causal factors—heredity, environment, and variation—occupy the center of the stage of controversy at present. This is not always understood, so thick is the smoke of altercation.

Several significant facts, however, should be quite clear. One is that some kind of "variation" must lie behind organic evolution, which means a development from lower to higher forms. A haphazard or a fixed environment cannot account for improvement in organic structure, nor can the laws of heredity, strictly considered, which apparently allow for no changes except those already existing in the specialized ancestral stock. Where evolutionary changes are accounted for under "inheritance," some kind of variation is taken for granted.

The real difference of opinion regarding the causes of evolution has, after all, been over the meaning and extent of variation, the other factors (though considerably clarified in the discussion of the last half-century) being used almost entirely to indicate the limitations that must be imposed upon the variational process. Lamarck gave a very wide meaning to it (the fact of germinal continuity being entirely unknown then), his main contribution lying in his suggestion that behind variation is a psychological desire or urge on the part of the organism which not only causes it to adapt itself to its environment but also enables it to secure an ever-expanding freedom. Darwin stressed the significance of environment as determining what variations shall or shall not survive; only those best fitted are passed on, the rest perish in the struggle for existence. Thus by the continual natural selection of the best adapted, each new generation raises the selective process to a higher level because of never-ceasing variation. Weismann insisted that not even all those variations that survive in the struggle for existence are transmitted to offspring, but only those which have themselves been inherited and not acquired. Vries has proved that there are certain variations (mutations) which apparently arise quite apart from inheritance and which breed true thereafter, and he suggests that evolution proceeds not by gradual selective changes due to environment but by sudden transforming jumps. And yet, is there anything in the suggestions of Darwin, Weismann, or Vries which indicates *how* variational changes that may be either "backward" or "forward" (whether they occur in jumps or gradually) are transformed into an evolutionary process that moves from lower to higher forms? The only suggestion that strikes deep enough is the one of Lamarck, the one that has suffered so much ridicule because it is tied up with his erroneous belief that acquired characteristics can

be immediately transmitted—the suggestion that behind variation of an evolutionary sort is a psychological urge or desire which, within the limitations set by environment and inheritance, though ever and anon breaking through these limitations with a mutation, drives organisms on to higher and ever higher goals.

All this controversy is with respect to organic evolution in general. The significance of Lamarck's suggestion becomes even more pertinent as the problem is applied directly to man. The lower animals exercise no control over heredity and environment. With man the situation is quite different. It is possible for him to master heredity by preventing the transmission of degenerate stock and encouraging the propagation of the best; and with respect to environment, his power is even more significant. In fact, with man's advent, Darwin's law of selection comes to a logical end. No lower organism is now capable of successfully competing with *Homo sapiens* for survival. The whole of animal creation, aside from a few micro-organisms, is at his beck and call. As for man competing with man, the plane on which humanity struggles is not a natural but an artificial one, as we shall have more occasion to discuss in the final chapter. No longer is it a question of blind adaptation to a given environment. Man adapts himself with intelligence, is able in large part to choose the surroundings he likes best, and is proceeding to fashion a society closer to the heart's desire. He will always be limited by natural law, but he is also utilizing nature's forces to make his world more livable and beautiful. Environment he has in many respects conquered; heredity he can direct if he will; only variation remains beyond his control.

To the determinist (the believer in mechanistic fatalism), variation is a blank enigma, especially since the discovery of mutations. To the libertarian (the believer in free will), it

is an expression of the creative force which within the limitations of heredity and environment—limitations it itself has set in its millennia of terrestrial unfoldment!—has been pushing onward and upward to more and more complex self-realization, and which in man has reached the highest expression thus far attained.

After all, the biologist alone cannot completely determine the causal factors behind evolution. He has clarified the meaning of heredity, environment, and variation, but he must look to the psychologist and sociologist to go further; and these if they are wise will begin with the facts established by the biologist.

We have arrived at the outposts of modern biology and must not forget the substantial body of achievement that lies behind. Hardly two thirds of a century have elapsed since the path to biological progress was cleared of medieval misconceptions (of catastrophes and special creations) and the three generalizations were launched (regarding the germ layers, the cell and protoplasm, and the fact of evolution) which gave the science a solid footing. And since that day, besides the attack upon the causes of evolution, every branch of biology has seen a marked advance, comparative and histological studies have gone forward apace, and the new sub-science of genetics has taken its rise. The importance of the latter for social problems has already been touched upon.

§ 6

The science of life provides man with the materials for a considerable additional mastery over environment, additional to that provided by the physical sciences and geology, the most important practical use already made of it being in the control and elimination of disease. Mankind has been increasingly protected against plague and epi-

demic. Smallpox, yellow fever, typhoid, and even tuberculosis are no longer public health menaces. The average span of life has been increased. A better understanding of glands is providing new vitality for the aged.

Other important use has also been made of biological science, as in the artificial breeding of plants and animals. Existing stock has been improved, and entirely new varieties have been created to satisfy man's needs. But the wider and more important application of biology to prevent the propagation of the unfit, provide for the better mating of normal humanity, mark out the capacities and limitations of the individual, and solve insistent social problems such as too rapid population increase, has hardly begun. On these matters the reader should consult Wiggam's "New Decalogue of Science" and "The Fruit of the Family Tree." That author's plea to the statesman to apply the lessons of biology to social affairs is still to be heeded. Social problems, however, cannot be solved by the biologist single-handed. This will become more fully apparent as the findings of modern psychology are passed in review.

CHAPTER XIII

MODERN PSYCHOLOGY

§ 1

In the epoch-making writings of William James (1842-1910)—successful physician, eminent philosopher, and much-beloved Harvard professor for many years—the modern period in psychology may be said to have taken form. His "Principles of Psychology," in two volumes, was first published in 1890. Even to-day, though a considerable advance has been made in the last third of a century, there is no better introduction to the subject, unless it be his own abridgment, in one volume, which appeared two years after his larger work.

James defined psychology as the "description and explanation of states of consciousness," such, for example, as sensation, reasoning, decision, desire, emotion, volition. Attempts have since been made to improve upon this definition, substituting the study of "mind" or "behavior" for "states of consciousness"; but, everything considered, most of these later attempts fall short of the definition indicated above. Some short-sighted students have, to be sure, arrived at grotesque results because of a circumscribed view of "states of consciousness," such as the absurd attempt to divest man of all individuality and give him less unity than is assigned to a cow or a tree, by viewing him as a bundle or aggregation of ever-changing mental states and nothing more.

To say that psychology is a study of states of conscious-

ness does not imply that such states are all there is to man. In the first place, man has a biological constitution—a body—just as any lower animal has. In the second place, with respect to his psychological constitution—which we need not hesitate to call his "ego" for short, so long as we do not attach any mystical significance to the word—it is recognized to-day that there are subconscious as well as conscious elements. Thirdly, man's ego and his body are closely associated; they come together at the one end in *sensation,* through the organs of sense, and at the other end in bodily activity or *behavior.*

The layman says man has a mind, a heart, and a will, meaning that he thinks, feels, and determines upon courses of action. The layman is quite right in this concise statement regarding man's threefold psychological nature; and those present-day students who designate psychology as the study of the "mind" are wrong in that they emphasize one psychic phase at the expense of the other two. As for the term "behaviorism," which is thought of by some as about to do for psychology what evolution did for biology, there is still less excuse for its employment to designate psychic activity. What, in brief, does behavior imply? Man behaves when he moves his head, walks down the street, talks to a friend, writes a letter. He acts in these and other ways, as a result, we say, of psychological factors. A horse shakes its mane, starts off at a trot, eats its oats. It is also behaving, and we now infer, since the days of Darwin, that behind its actions there are psychological factors at work too. A tree behaves in putting forth its buds or clothing itself with green leaves in the spring. Does this organism also have feelings and thoughts behind its actions? We wonder. But observe that in all these examples behavior is the result or at least the concomitant of actual or inferred psychological activity; it is not the inner activity itself. It is something that follows

after or goes along with thinking, feeling, and willing. It is not a substitute for them. We have had occasion to see how the study of fossil remains aids in an understanding of living organisms. A study of behavior should likewise aid in an understanding of the psychological ego. But behaviorism is no more psychology than paleontology is biology.

Let us carry this common-sense reasoning a step further. We wonder whether the tree has an ego, and we infer that the horse has, because of their respective activities. Have we any reason whatsoever for the wonder and the inference except as a result of conscious human experience? None at all. It is here alone that we are made aware that there are such factors in the universe as psychological ones. Without states of consciousness, common to all men, there would be no basis for reasoning processes or for attempting to interpret behavior anywhere. We observe the behavior of others, just as we observe anything else in the world about us—through this human consciousness. Behaviorism presents nothing new; it is something we have already made use of (as in the physiological, embryological, and genetic studies in the preceding chapter) and which we shall continue to use where it is of value; but to put it forth as a substitute for the study of consciousness or the ego is merely to obscure the whole matter. The only improvement we have thus far made upon James's definition of psychology is to add a study of subconsciousness to that of consciousness. It would be better still, perhaps, to say that psychology treats of the conscious and subconscious ego and of its origin and evolution.

Sensations, as brought to man by sense impression or observation—the significance of which was analyzed in some detail at the end of Chapter VIII—are the beginning of his knowledge of environment. Observations of nature have been organized into a coherent scientific system, as

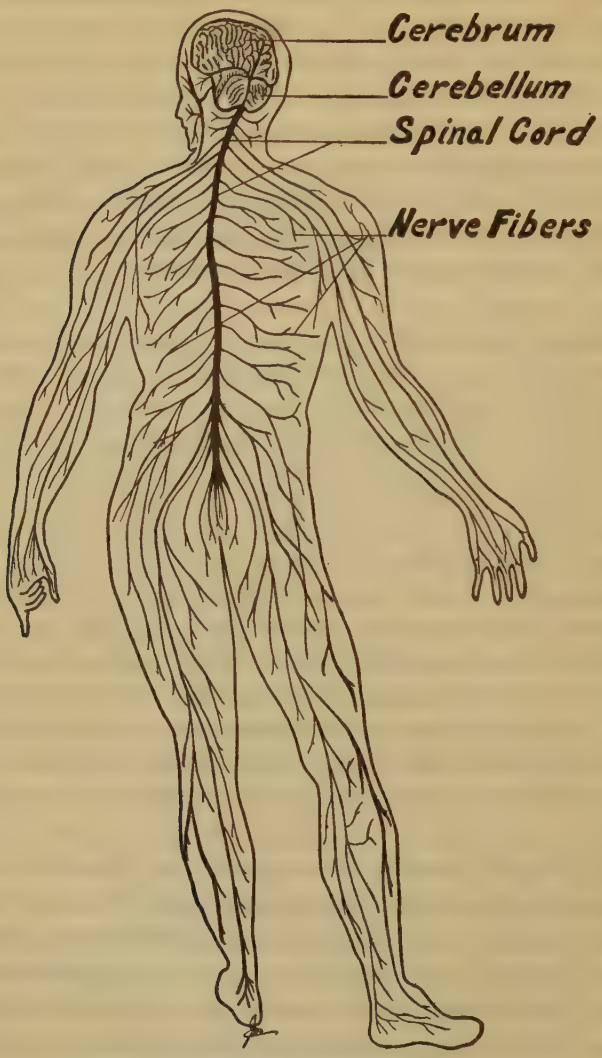
has been explained in preceding pages, by an analysis of the most general and abstract sensations first (in mathematics), then of those regarding physical phenomena (in physics and chemistry), then those pertaining to the universe at large (in astronomy), to the earth in particular (in geology), and to life on earth (in biology). At each new stage, the observational data have become more and more concrete and intimate, until man's own body has been included; and, now, in psychology, we arrive at an analysis of that activity through which the observational data are gathered and through which they are transformed into orderly knowledge. Here, then, are the most intimate and concrete phases of man's conscious experience, the observational and sensory processes themselves and the higher psychological processes in thinking, feeling, and volition, to which at least in part the elemental sensations give rise.

Man's psychological organization, as has been said, is fed and enlarged by sensation at the one end, and it results in organic activity or behavior at the other. Here it will be well to make clear the important hypothesis of psychophysical parallelism which James makes the basis of modern psychology. It has been found that the nervous system, comprising the brain, the spinal cord, and the nerve fibers that connect the cord and brain to the sense organs and extend to every portion of the body, plays a distinctive rôle in psychological activity. It appears that, so far as is known, mental processes are accompanied by concomitant biological changes in the nervous system. For every psychological condition there appears to be an accompanying neural condition. On the biological side, there are nerve fibers that carry incoming impressions from the sense organs to the cord or brain; there are the central organs (brain and spinal cord) through which these sense impressions are gathered up; and there are other nerve fibers that carry outgoing cur-

rents to muscles, glands, or tissues and stimulate them to action. Accompanying this biological system is a psychological system: the incoming sensations; the central conscious awareness, feeling, and judgment or their subconscious "prototypes"; and the outgoing volitions. These two systems run parallel, it appears, and the facts of psychology can best be visualized in terms of this parallelism, even though it represents a hypothesis which has not as yet been verified at every point. As James expresses the matter:

> The immediate condition of a state of consciousness is an activity of some sort in the cerebral hemispheres [which are the largest portions of the human brain, filling the entire upper cavity of the skull]. This proposition is supported by so many pathological facts, and laid by physiologists at the base of so many of their reasonings, that to the medically educated mind it seems almost axiomatic. It would be hard, however, to give any short and peremptory proof of the unconditional dependence of mental action upon neural change. That a general and usual amount of dependence exists cannot possibly be ignored. One has only to consider how quickly consciousness may be (so far as we know) abolished by a blow on the head, by rapid loss of blood, by an epileptic discharge, by a full dose of alcohol, opium, ether, or nitrous oxide—or how easily it may be altered in quality by a smaller dose of any of these agents or of others, or by a fever—to see how at the mercy of bodily happenings our spirit is.

Psychologists cannot now conceive of the ego as functioning apart from the neural mechanism that accompanies it. (But this does not preclude the possibility of the existence of "spirit" quite aside from psychological considerations.) Conversely, they maintain that wherever there exists a neural mechanism, whether in man, beast, or lower organism, we may fairly assume that a psychological process runs parallel to it. In the light of this far-reaching hypothesis, our wonder regarding the tree's "ego" can be answered.



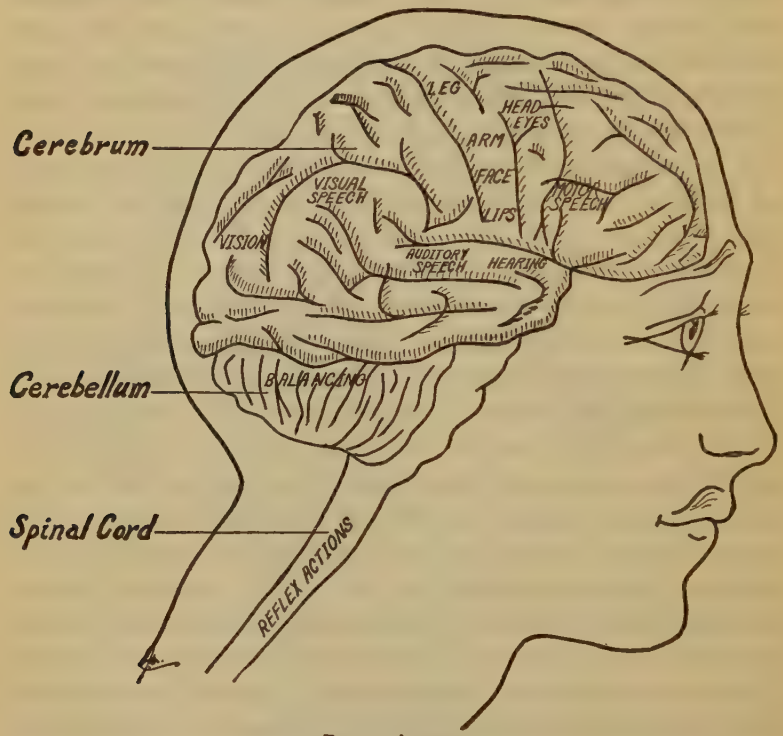
THE NERVOUS SYSTEM
(a considerably simplified diagram of its main parts)

The tree has no nervous system; it cannot, therefore, have a psychological organization. The higher animals do have neural mechanisms, so that we regard them as possessing "egos," even though we can never know this with absolute certainty, since only human beings convey their thoughts and feelings to us through language. Herein lies the value of behaviorism. Through a study of animal behavior many important though second-hand facts of psychological value have been brought to light in recent years.

Our present knowledge of the human nervous system is of wide extent. The accompanying diagram of its various branches gives some idea of its intricacy. It will be observed that the most important part of the system, the brain, is composed of two main sections: the cerebellum at the lower part and, at the top, the cerebrum, which is made up of the two cerebral hemispheres that William James speaks of as conditioning our states of consciousness. Below the brain is seen the spinal cord, from which radiates a network of nerve fibers, some of the motor type leading out to the muscles, tissues, glands, and the like, and others of the sensory type leading in from the sensory organs. The nervous system is spoken of as having a central branch, associated in the main with conscious activity, and an autonomic branch associated chiefly with those internal bodily functions—circulatory, respiratory, digestive, secretive—over which we exercise little or no conscious supervision. The central and autonomic divisions are nevertheless closely connected, our conscious activity having marked effects at times on autonomic reactions, and the internal condition of our bodily functions being reflected in conscious and subconscious states. A few paragraphs descriptive of the ramifications of this marvelous biological system through which man's every activity—organic, subconscious, and

conscious—is controlled, will make clearer its primary significance for psychology.

The behavior of frogs and other animals in which various portions of the nervous system had been removed, and the



BRAIN AREAS

post-mortem dissection of the brains of persons who had been insane or otherwise mentally deficient, have revealed the functions fulfilled by different divisions or branches and have enabled physiologists and psychologists to plot the areas of the brain given over to various specialized purposes. The cerebral hemispheres of the cerebrum are thus found to be the centers for all consciously experienced and

consciously directed activity. The outer surface of the cerebrum, as every one knows who has on occasion purchased calves' brains at the butcher's, is composed of folds or convolutions and provides a large area upon which impressions of one kind and another that arise out of sensation or otherwise may be registered. The physical prototypes of our remembrances, thoughts, and feelings are stored here. We direct our conscious bodily activities through this region. We speak, hear, see, touch, taste, smell, by virtue of various cerebral areas set apart for the purpose. The diagram on the opposite page illustrates these facts.

If a frog is deprived of its cerebrum it does not cease to live, but its actions become wholly automatic. It shows no fear, hunger, or desire of any kind. It will swim if placed in water; eat, if food is put in its mouth; jump, if touched; croak, if stroked; but it seems to have completely lost its spontaneity. Its behavior is no longer self-directed. Experiments of this nature have demonstrated that habitual, automatic, and reflex movements in man and other animals are controlled directly through the cerebellum and the spinal cord, and that accompanying nerve currents are short-circuited before reaching the cerebrum.

The autonomic branch of the nervous system takes care of organic and other automatic reactions. It has three divisions: the cranial, radiating from the upper end of the spinal cord; the sympathetic, issuing from the middle section; and the sacral, from the lower end. A close relationship has now been established between pleasant and unpleasant sensations and these autonomic sub-branches, the craniosacral acting together to stimulate the pleasant reactions accompanying digestion and sex behavior, and the sympathetic division inhibiting such reactions. The latter is closely associated with unpleasant excitement, that which accompanies fear, anger, and pain.

In the formation of habits such as swimming or piano playing, the movements are at first consciously directed, the sensory and motor nerve currents accompanying them passing up to or out from the spinal cord, cerebellum, and cerebral hemispheres. Later when the actions have become second nature, their detailed supervision is transferred from the cerebral hemispheres to the lower centers—the cerebellum and spinal ganglia—while through the higher centers cognizance is taken only of the habitualized movement as a whole, or no attention is paid to it at all unless something goes wrong. The ego is thus constantly relieving the cerebrum of unnecessary attention to details and focusing its activity upon that which is of most importance to the economy of the whole organism from moment to moment. A wonderful system indeed, and the more it is studied in relation to the functions it fulfils the more marvelous does it appear.

A word may be added regarding the organs of sense through which the ego comes in contact with the external world. It is to be expected that, to serve their purpose best, the sense organs would be situated, as they are, on the outer parts of the body. Besides the five senses commonly known, modern psychology has discovered a number of others, notably those of pressure, temperature, and pain. Special nerve endings, situated at different points under the skin, carry the respective sensations inward along the sensory nerves. There are tactile nerve endings located all over the body but by no means evenly spaced. There are areas of nerve buds sensitive only to pain; others, only to pressure; others again, only to heat or cold. Taste buds are situated on the top and back parts of the tongue, and smell centers in the lining of the upper part of the nose. Experiments have shown that the senses of smell and taste are often associated and thus confused. If the nostrils are held, it

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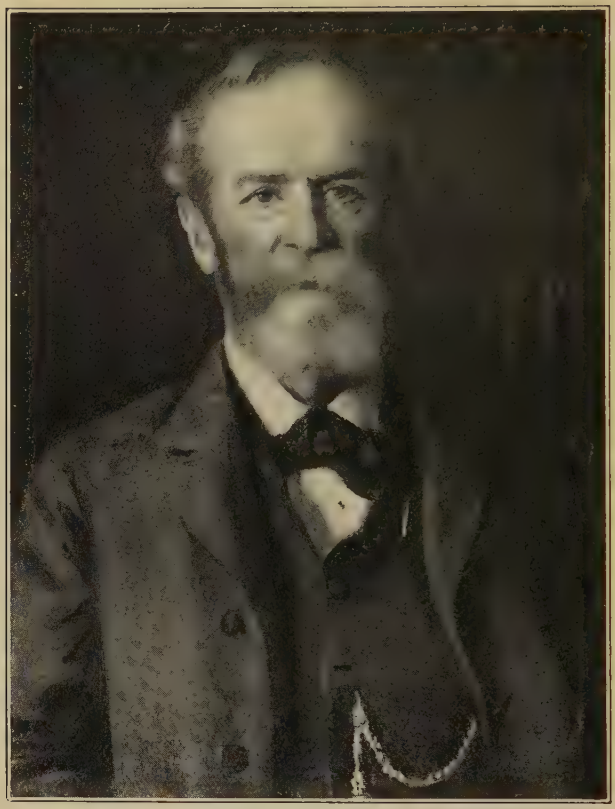


WILLIAM JAMES

will be found impossible to distinguish between the taste of apple and onion pulp or of solutions of coffee and quinine. Most flavors are compounds, elemental or true tastes being sweet, sour, bitter, and salty.

The most important and most highly specialized sense organs in man are those associated with sight and hearing. The eye and the ear are very delicate and intricate mechanisms. Like the camera that is fashioned after it, the eye has in front a lens through which much or little light is allowed to enter by means of a kind of shutter. Light-waves entering the normal eye are focused at the back of the eyeball upon the retina, a delicate photographic plate, from which the impressions are carried by way of the optic nerve to the brain. In near-sightedness and far-sightedness it is necessary to add artificial lenses (eye-glasses) to the natural lenses of the eyes to secure a proper retinal focus. With respect to the ear, there are three main parts, outer, middle, and inner. The outer part is funnel-shaped, so that it may the better catch the sound-waves, and is separated from the middle ear by the well known tympanum or ear-drum, a tightly stretched membrane upon which the sound-waves impinge. The vibrations are thus transmitted to the middle and inner ears, where they pass through delicately constructed canals and labyrinths to the auditory nerve which in turn conveys them to the brain. The middle ear is connected with the mouth cavity through the Eustachian tube, which supplies air pressure to the back of the ear-drum. The inner ear is a most intricate mechanism and contains a device for the maintenance of bodily equilibrium and balance.

In this brief account of the nervous system, we have been viewing the subject-matter of psychology mainly from the biological side. For the sake of brevity and simplicity, no attempt has been made to indicate meticulously the con-

comitance of psychological and neural states which is thought to exist at every point. The reader should, however, keep this parallelism constantly in mind. Possibly these two synchronous systems are at bottom but two sides of the same shield, the dualism of mind and matter being likewise only apparent. But such speculations are metaphysical. They do not concern us in present-day psychology, for they are unnecessary there and only obscure the fundamental facts. Modern psychology accepts as working hypotheses the broad dualism of mind and matter and the more particular parallelism of psychological and neural changes. On this basis it proceeds to build up an orderly system of scientific facts.

In the light of psychophysical concomitance, the intimate dependence of psychology upon biology becomes clear. Until the anatomy and physiology of the human brain, spinal cord, nerve fibers, and sense organs had been worked out, it was impossible to arrive at a scientific perspective in the field of psychology. And the analysis of the human nervous systems proved to be but a beginning. Comparative and genetical studies have of late become of increasing importance in psychology as well as in biology.

§ 2

The foregoing sketch is of psychology as it now is. At the beginning of the nineteenth century, however, very few of its features were known. The mental philosophers of the Bacon-Hume school on the one hand and of the Descartes-Kant school on the other were still engaged in their futile efforts to resolve metaphysical speculations to manageable terms and to establish the primacy of mind over matter or of matter over mind. The dualism of these two elements was not accepted as a working hypothesis for psychology till the nineteenth century was well under way, and the still

more important hypothesis of the psychophysical parallelism did not take hold until the last quarter of the century, when psychology became finally divorced from metaphysics. But this does not mean that even to-day all psychologists have freed themselves from fruitless speculative encumbrances.

Through the nineteenth century the mental philosophers remained oblivious of the inadequacy of the facts with which they were working and of the untrustworthiness of their method of approach. It will not be profitable here to follow their discussions further.

The real impulse for a more scientific approach to psychology did not come from the mental philosophers at all but from certain physicists and physiologists who in the early part of the nineteenth century studied the construction of the eye and ear, devised appropriate methods and instruments for measuring the biological changes accompanying sensations of various kinds (such as changes in blood-pressure, respiration, muscle response, glandular reactions, and rate of flow of nerve currents), traced the positions of the sensory and motor nerves, and discovered the psychophysical parallelism. Outstanding among these early experimenters were Weber and Fechner, and also Müller and Helmholtz, whose contributions to physics and physiology we have discussed elsewhere.

The man who finally brought together the work of these physicists and physiologists and that of the mental philosophers was Wilhelm Wundt (1832-1920), a German physiologist and psychologist, who in 1874 published a memorable book entitled "Physiological Psychology." Five years later he established at the University of Leipsic the first definitely recognized psychological laboratory and thus started a movement which spread rapidly to America and to the rest of Europe. Wundt is rightly called the father of

modern psychology. He gave emphasis to the psychophysical parallelism, advanced the idea that psychology deals with human experience just as the other sciences do, and insisted that the scientific method is applicable in this field as in any other.

Besides pursuing their predecessors' experimental studies on the relation of physical stimuli to conscious sensory experience, Wundt and his followers attacked the problem of psychological "taxonomy," devising a descriptive system of classification, as Linnæus had done for biology. They arranged sensations of light, sound, smell, and the rest according to some obvious scheme of likeness or degree of resemblance. They analyzed compound sensations into more elemental forms, as in the differentiation between smells and tastes that has already been noted, and examined the compounding of elemental sensations into so-called blends or patterns, such as the taste of lemonade or the sound of a musical composition. A similar process of analysis and classification has been applied by the Wundtian school to conscious states of perception, memory, imagination, reasoning, feeling, emotion, attention, and volition. Although some of these are less amenable to conscious control than are sensations (experimentation therefore resulting less favorably), significant progress has nevertheless been made even here.

As a result of these labors it has become possible to indicate the relationship existing between various states of consciousness. The Wundtians regard sensations as abstract elements out of which more complex and real forms are compounded. The human ego, they say, experiences in consciousness no pure sensations. These always appear to us in combination and conditioned by previous experience. The color red, for example, is not seen disconnected from concrete things. What we see is a red book or a red hat,

and in the sight sensation is wrapped up an awareness that inside the book are pages or that the hat is made of a certain kind of material. Sensations arise in our minds tinged with other sensations and fraught with meaning. As we experience them, they are, in short, *percepts,* in which a well rounded *image* of the thing perceived and an *idea* as to its significance, as well as other factors to be mentioned presently, are combined into a very complex whole. Sensations are elements of consciousness, to repeat, which are arrived at only by abstraction.

A perception is believed to carry with it on the neural side an impression in the brain tissue, making a groove, let us say, as a seal leaves its stamp in sealing-wax, except that the registration is not so permanent. It fades out after a time unless restimulated by another sense impression from without or by an "act" of *memory* from within, the latter phenomenon dimming the image part of the remembered perception and emphasizing the idea part. Ideas are thus thought of as arising out of sense impressions (perceptions), but, once created, as being free (though accompanied, of course, by some kind of brain excitation) to roam the mind at will; they often take leave of past experience and give rise to *imagination* or *fancy.* They may also be arranged, combined, and rearranged in an endless variety of ways. When ideation occurs in strict accordance with actually experienced perceptions, it is called constructive imagination. When it deviates from experience and, for example, connects a lion's head with a tree's trunk, it is called fancy. But it is hard to draw a fine distinction here. What part of our day-dreaming and castle-building is constructive and what fanciful, it is difficult to say.

The *reasoning* process involves sensation, perception, memory, and imagination; but its most characteristic element is the combination of percepts into concepts that are

almost entirely freed from particularities and result in generalization. When I say that I prefer to write with a pen, the statement sounds concrete enough, and yet no particular pen-percept need be implied. I may mean any suitable pen, and you can call to mind half a dozen kinds. Such a word as "pen" stands for a general class, nor would we get very far in thought communication if we were tied down to particulars. Herein lies the great virtue of language, which marks off man so definitely from the lower animals. Words tend to free thought from particularity and in their combinations enable the human ego to rise from perception to conception, hypothesis, and generalization. This, in fact, if done in strict accordance with experience, is the essence of scientific reasoning.

So much for the thinking side of the conscious human ego. There is, however, more to a perception than a mixture of sensations plus a meaning. There is also a *feeling-tone* attached. Every percept impresses us as either pleasant, unpleasant, or indifferent. Many theories have been put forth to account for feeling-tone, but none of the Wundtian explanations are satisfactory. All we can say here is that there are feelings, usually very complex ones called *emotions,* and that they must not be overlooked in a description of states of consciousness. The sight of a poisonous snake met suddenly on a tramp through the woods arouses much more than a mere perception. The warm reception we accord it—or our hasty departure—bespeaks the presence of a strong emotion. Fear, anger, hate, love, grief, are some of the more potent feelings aroused by various sensations and experiences. Each of them is represented by a noticeable biopsychological excitement that penetrates to the very depths of our being. A static description of such processes falls far short of rendering any adequate account of their meaning.

The ego, in perceiving, knows and feels. In addition, it decides what it shall perceive and what it shall leave unperceived. Innumerable impressions are constantly bombarding the sense-organs, whether we sleep or wake. But only a few secure the ego's *attention.* Some of them impinge on the sense-organs and bring about reactions, reflex or habitual, over which the conscious ego exercises little or no control. Others impinge and register but leave the ego indifferent to them. Still others secure its attention and result in conscious perception.

What the ego shall or shall not attend to lies very largely within its so-called power of *will;* but this does not mean that it is free to will wholly as it pleases. The ego cannot by an attempted act of determination fly to the moon, abrogate magnetic attraction, or grow an additional arm. It is bound by the laws of the natural world without and of its own constitution within. On the other hand, the conception that the ego merely imagines it makes decisions, and that every act is decided for it in advance, is likewise meaningless. Metaphysical speculations here as elsewhere must be avoided. Psychology cannot go behind the tacit acceptance of the very obvious common-sense fact that within certain well defined limits the ego deliberately chooses between alternatives; that is, exercises freedom of will.

It is confidently held to-day—though on other grounds from those supplied by the Wundtians—that the prime purpose of perceptions, acts of memory, imaginings, reasonings, and emotions is to enable us intelligently to control our conduct, such control being brought about by the will. What the ego shall decide to do is also conditioned by those inner drives or interests which grow up around inherited dispositions, environmental influences, and group compulsions. But these considerations belong to another part of our story.

Psychology under the influence of Wundt has received an important forward impetus. The contributions of the physicists, physiologists, and mental philosophers have been consolidated, and the work of analysis and description has been furthered. The Wundtians provided, for the first time, a fairly adequate picture of the conscious human ego. Yet their work represents but a preliminary step on the road to scientific mastery in psychology. Just as the Linnæan classification in biology was wholly static, and came before comparative, histological, embryological, and genetic studies pointed the way to a more satisfactory approach, so was Wundt's contribution. His school viewed the human ego on its conscious and structural sides only. What was needed, in addition, was a functional and genetic approach and an understanding of processes that operate below the fringe of consciousness. Beyond psychological statics lay psychological dynamics. The contribution of the school of Wundt was, in fact, but one of several streams of activity which were converging after the third quarter of the nineteenth century to raise psychology to a scientific plane.

§ 3

A second stream of major importance for psychological advance, caught up into the main current after the publication of William James's "Principles" in 1890, is the study of psychic abnormalities. Psychopathology has become increasingly popular in recent years because of Freudianism, Couéism, and spiritism, and has enlisted the aid of a large number of serious students. Its beginnings, however, had to do not with psychology but with the study of medicine.

Two widely separated developments toward the close of the eighteenth century mark the inception of a rational attitude toward the mentally and emotionally abnormal: one vividly depicted in a famous painting wherein the

eminent physician Pinel strikes the chains from the insane inmates of the Salpêtrière in Paris; the other growing out of experiments in hypnotism by another physician, Mesmer by name, first in Vienna and then also in Paris.

Pinel's dramatic action betokened a drastic change in attitude toward the insane. He insisted that these unfortunates are not possessed of devils or any other kind of demon, as had theretofore been generally believed, but that they are mentally diseased and, just as the physically sick, are in need of treatment. The success of his methods in Paris caused the movement for less restraint to spread to other institutions and led to the establishment of psychiatry as a branch of medicine dealing with the diagnosis and treatment of mental disorders.

With the later rise of brain physiology, insanity came to be thought of as almost entirely a disease of the brain. Post-mortem examinations have, in fact, revealed many lesions and disintegrated tissues and have aided greatly in localizing the brain areas associated with different psychological functions. More recently, however, it has come to be recognized that not all types of insanity can be traced to brain deterioration and that the methods brought into prominence by the hypnotist Mesmer have diagnostic and curative value in psychiatry, just as, in the meantime, they had proved themselves of value in the treatment of another group of nervous disorders, the psychoneuroses, of which hysteria is the most widely known form.

A century and a half before the late Emile Coué aroused the masses of Europe and America with his many cures and his "every day in every way" maxim—in the year 1922 he is said to have treated forty thousand patients!—Mesmer was drawing attention to himself for a similar reason. Coué began by using hypnotism to effect cures and then turned to autosuggestion. Mesmer apparently used only the

method of hypnosis, which he thought of as a kind of animal magnetism passing from him to the patient. His séances, staged like those of a modern magician, created a stir in Paris and resulted in an investigation by a royal commission, which, though skeptical in its findings, could not accuse him of fraud. A number of attempts were later made to understand hypnotism, culminating after the middle of the last century in a historic controversy between two noted French physicians, one of them Charcot, which resulted in the definite establishment of hypnotism as a method of diagnosing and treating certain nervous ailments. Charcot's name is especially prominent here, particularly in the treatment of hysteria, two of his pupils, Freud and Janet, carrying the work of the master into the present century.

In Charcot's day the attitude of the medical profession toward hysteria and allied ailments was the attitude of a father toward a naughty child. A good spanking was thought to be what was needed, but since it could not be considered exactly in order to consign grown-up women to the whipping-post, "strong electric shocks, cold douches, and other decorous substitutes for a sound birching," says McDougall, were prescribed. Thanks to Charcot and his disciples, all this has changed. Hysteria is now recognized as a form of "dissociation of personality," a small or a larger stream of mental or emotional activity functioning independently and in disregard of the main stream, and at times entering into rivalry with it. Here, for example, is a woman who goes into hysterics every time she hears the sound of a bell, whether front-door bell, telephone bell, or church bell. She knows she is affected in this manner but has no power of prevention or control. Subjected to hypnotism or to some other form of psychoanalysis at the hands of a skilled practitioner, the patient is found to have gone

through a violent emotional upheaval years before while a church bell was tolling; let us say the experience occurred at the time of the death of a loved one. Years have seemingly healed the emotional wound, and its connection with a bell has been entirely forgotten, when suddenly the hysterical neurosis develops. Similar emotional symptoms, such as a fear of cats or shut-in places, have likewise been traced to some upheaval associated with the loathed object, an experience dating often from early childhood. The cure is usually as effective as the diagnosis is startling. Merely confronting the conscious mind with the forgotten emotional experience and deliberately associating it again with the bell or cat or what not, has often served to "reintegrate" the personality. The small stream of independent activity is thus brought again into harmony with the rest of the ego and may prevent any further disturbance.

But sometimes the dissociation is more extensive, a very large stream of activity splitting off from the rest of the ego to function independently. The result is dual or multiple personalities, so called, and their reintegration may be exceedingly difficult if not impossible. The famous case of a Massachusetts girl, reviewed by Morton Prince in his book entitled "Dissociation of a Personality," is still read with fascinating interest. Most instances of an insensitive arm, which does not respond to ordinary sensation or volition but engages in automatic writing without the knowledge of its possessor, or of a man who disappears from home, starts life over again in some distant city wholly oblivious of his past career, then "comes to himself," forgetting in turn his new existence but remembering everything that went before, after which at intervals of some weeks' or months' duration he alternates back and forth between his two selves—these and like occurrences have been definitely traced to causes similar to those inducing hysteria. The planchette and the

ouija board have brought to light unexpected streams of dissociated activity in many otherwise normal individuals.

Interesting theories to account for these psychoneuroses, whether mild or more serious, have been advanced by Charcot's disciples, especially by Janet in France and Freud in Austria. Janet assumes that each ego possesses a unifying activity which normally brings together into one well balanced system all its various experiences, and that in neurotics this unifying process is defective. Freud lays emphasis on the fact that in the constitution of every ego there are many diverse impulses, some of them in conflict with others, and that most normal individuals are subject to conflicts, commonly known as temptations, which if faced resolutely and consciously may be overcome without causing further difficulty. By frankly recognizing a temptation as "an expression of a lower possibility of our nature," the higher or moral forces subdue it and rule supreme. There are then no mutinies below deck. But some people refuse to acknowledge a vagrant impulse for what it is. They will not face it in open combat. The moral nature never comes to grips with it. The horror of admitting the existence of such an impulse occasions its peremptory repression. Consigned to the lower regions without its day in court, the unwelcome tendency "schemes" to get by the rigid censorship maintained above, and so in dreams and reverie or in a neurosis it manifests itself, usually in some symbolic form that it may escape recognition and summary ejection. Freud stresses the emotional and volitional phases of neurotic disturbance; Janet, the rationalistic: both views seem to contain considerable truth, though the Freudian is the better known and has been applied with more uniformly helpful results.

Many criticisms have been and are still being urged against the Freudian psychopathology, but largely because

of Freud's extreme beliefs in the matter. It is just as certain to-day that not all dreams are caused by suppressed impulses as it is that some of them are. There is, furthermore, on the part of the Freudians a tendency to blame all neurotic conditions on a suppressed sex desire. It has in truth become increasingly evident that the sex impulse plays a larger part in the emotional experiences of most people than has generally been admitted, but it is also evident that there are other innate tendencies of great importance and that no one of them possesses a monopoly in producing neurotic upheavals. Into these criticisms we cannot enter further here. What should be emphasized, however, and emphasized strongly, is that, regardless of the extreme views held by Freud, he has performed a notable service to humanity, in the many cures he has effected, and to psychology in stressing the dynamic character of subconscious processes. An unexplored emotional world has been opened up by the psychoanalysts, and of late their methods have been increasingly utilized by the psychiatrists, who have come to recognize many forms of insanity as of the same origin as the psychoneuroses. If more present-day psychologists had the courage and insight of William James, who first stressed the immense significance for psychological advance of a study of hypnosis and the subconscious, there would be less bickering and more solid achievement.

What are some of the vistas opened up by psychopathology for a further understanding of the normal human ego? The prospects are so immense and astounding that timid souls among the psychologists, fearing to face the ridicule of their associates, may be forgiven for hesitating to accept them. Hypnosis has not merely cured unfortunates of their neuroses. It has also proved beyond further peradventure that each of us has a subconsciousness as well as a consciousness; that much of our psychic

activity goes on below the surface and only on occasion or when needed rises to the plane of awareness; that experiences are in part assimilated, problems solved, decisions made, and volitions carried out in these lower regions; that the normal influence exercised by the mind over the body is but the smallest fraction of what is possible; and that mind can probably communicate with mind in some "direct" fashion and without the intervention of the senses or other ordinary means of communication.

Hypnosis has revealed that impressions reaching the sense organs from the outside world, or as a result of inner organic activity, register whether we are aware of them or not, and that a probing of the subconscious will elicit astonishing details of past experiences regarding which the conscious ego has never been cognizant. A person told in a hypnotic trance to perform an incongruous act, such as purchasing a hundred corkscrews of varying sizes at a stated future time, and having no later recollection of the mandate, will not only perform the action at the time indicated but will as a rule evolve a perfectly plausible reason for doing so. How this train of purposive activity is developed in the subconscious is still a mystery, but there is no further reason to doubt the nature of the facts.

The oft-repeated assertion that we learn to swim in our sleep is now known to contain considerable truth. Flashes of wit arise from subterranean depths where a nice co-ordination has apparently been effected; and yet there is often no deliberate search for the words, and the person from whose lips they flow may be as much surprised as his listeners are amused. The sudden insight into a problem or the production of a masterpiece of art may have been the culmination of a long process of subconscious thought and preparation.

Whoever has had occasion to witness the cataleptic states

brought on by hypnosis, cannot come away without the feeling that the mind has powers of control over the body which are normally untapped. Mental healing may elude the understanding, but that some disorders have been completely cured through the power of suggestion is also a fact no longer open to question.

Direct communication of mind with mind is a contingency few psychologists can face with equanimity. There are now so many validated incidents which give color to the telepathy hypothesis that it would seem as reasonable to assume its legitimacy as it is to believe in wireless transmission or the ether. But the ramifications of such an assumption seem too amazing for most specialists. That our ideas may not be altogether our own but may be in part received "on the air," or that public opinion may be much more than a convenient democratic catch-phrase, opens up avenues of psychological development that seem indeed unlimited. William James believed in these possibilities, and we have discovered nothing since his day which might be regarded as contradictory. Truly, in so important a question, even more than ordinary vigilance should be exercised in verification. But we have had too much derision and foolishness in the matter. This is serious business for all of us. The scientific method of carefully drawn hypothesis followed by a thor oughgoing test offers the only solution here or elsewhere in the realm of science. As for the alleged phenomena of spiritism and mediumship, still so interpenetrated with conscious and subconscious deception that it is almost impossible to separate fact from fraud (with our present unscientific methods of control), nothing but the briefest mention can be made here. That these phenomena, where genuine, are to a large extent bound up with hypnotic suggestion is now well known.

Quite apart from spiritism and telepathy, however,

hypnosis and the new psychotherapy have thrown considerable light upon the constitution of the human ego. A fuller understanding of sleep, dreams, autosuggestion, and hypnotic influence is having a marked effect upon psychological theory. Of most importance here is the laying bare of the world of the subconscious. Although a complete exploration is still a matter of the future, the revelations of the psychoanalysts have already been revolutionary. The fact that normal man has suppressed desires, subconscious drives, and conflicting interests which escape his conscious knowledge and control, is one of the most important developments of the twentieth century. Human behavior can hardly be completely rational, ethical, social, and well balanced unless the subconscious is harmonized with the conscious life of man. Whether or not our conventional standards are wholly conducive to such harmony is a question that is now being investigated. The solution of some of our most pressing social problems depends undoubtedly upon a better comprehension of the subconscious. Its study thus far has brought us an understanding of the human ego quite different from that produced by the physiological psychologists. The school of Charcot has joined hands with the school of Wundt to extend our psychological knowledge.

§ 4

One aspect of the controversy stirred up by Freud points to a field of investigation still to be touched upon here. He insists that the sex impulse is the main drive behind human conduct. The majority of psychologists reply that there are many other impulsive drives in the human ego. What are these main drives, how do they function, and whence do we get them? This is a question which neither the Charcotians nor the Wundtians are able to settle. Its answer, however, has been attempted by a third group of specialists whose

activity, like that of the other two groups, was caught up into the main stream of psychological advance by William James. This activity constitutes the genetic or evolutionary approach to the subject.

For some years after the publication of Darwin's "Origin of Species," little constructive effort was made to apply the evolutionary hypothesis to psychology, despite the fact that Darwin himself suggested its applicability. He maintained that the ego has evolved just as the body has, and that a study of the mental life of animals, savages, and children should throw considerable light on the genesis and functions of the adult human consciousness. He contended, further, that the biological laws of natural selection, variation, and heredity apply with equal force to psychological development. Herbert Spencer, a noted contemporary of Darwin, also held such views and gave them wide dissemination through his popular writings. At first these ideas were violently opposed just as the idea of organic evolution was. Man's privileged position was being assailed, and the generally accepted dogmas of religion were being put into jeopardy. But gradually the opposition waned, and the value of the genetic approach to psychological problems came to be appreciated. After its emphasis by William James, a number of outstanding workers came to the fore to give it concentrated attention: men like E. L. Thorndike in animal behavior, G. Stanley Hall in child psychology, and Francis Galton, the propounder of the biological law of ancestral inheritance, in individual mental variations. Through the efforts of these men and their associates a considerable amount of additional material has been made available for a further understanding of the human ego.

As a result of the study of *animal* behavior, many false ideas regarding the differences between man and the lower animals have been swept away in the last third of a century.

It is no longer possible to say that man is governed solely by reason and the lower animals wholly by instinct. Some animals undoubtedly reason, and man has an abundance of instinct. The evolutionary process on the psychological plane is quite evidently continuous, and man is much more like his lower brothers than many still suppose. It is now generally held that states of consciousness are not the sole possession of man. There are students who go so far as to say that some form of consciousness extends throughout the whole organic world, down to the amœba and the plant; but most authorities limit it to animals having nervous systems and exhibiting certain types of intelligent behavior, that is, possessing the ability to learn through experience.

Experiments with animals have in the main been directed toward discovering what kinds of things they learn and how the learning is accomplished. In the case of wild animals very little real information has as yet been forthcoming, for the obvious reason that conditions of control are difficult. Excellent results, however, have been achieved with domesticated animals and with rats, rabbits, and guinea-pigs. By appealing to some powerful instinct such as hunger, it has been found, for example, that a famished cat can after repeated trials learn the trick of quickly undoing a complicated catch in a door behind which food is placed. Experiments of this nature have thrown such light on the inherited and acquired powers of animals as that flight in birds is innate but that the particular bird cries or songs are acquired from generation to generation.

Among the many lessons brought to us through a study of animal behavior, in the effort to determine how far and in what respect, if at all, man has progressed over his lower brothers in psychological organization, three points will bear particular emphasis. First, it is now clear that the same

kind of purposive activity exhibited by man is manifest throughout the whole animal kingdom. Much of animal behavior is strictly analogous to human behavior in the persistence with which, despite obstacles, it drives on toward those goals which the springs of life encompass. There are martyrs in the world of brutes just as there are in the world of saints, and the idea that human beings as a rule deliberately set out to seek pleasure and avoid pain becomes absurd in the light of what the lower animals do. Human and animal volition alike springs out of blind impulse, and only rarely even on the human plane is a course of action clearly understood, much less deliberately directed. Secondly, both men and lower animals come into the world equipped with many psychological "structures" of great complexity, with nicely adapted modes of instinctive behavior completely provided for. The animal world falls into two great classes in respect to native equipment: one, best exemplified by the insects, in which the innate endowment is highly complex and specialized, and in which little modification in behavior occurs after birth; the other, best exemplified by the mammals including man, in which the innate structure consists of very general instincts not highly specialized, and in which a great amount of leeway is provided for intelligent modification and adaptation to environment. Thirdly, psychic evolution appears now as the prime factor in progressive development, and change in bodily structure as a consequence rather than a cause. Biologists must look for the forces behind organic evolution in purposive inner powers which drive animals on to maintain their existences and propagate their kind. The ego, it appears, is not a by-product of later stages in the evolutionary process but the directing force behind it.

Yet, despite the discrediting of false notions and the positive accomplishments in the field of animal psychology

itself, the main problem of the essential mental differences between man and the lower animals remains unsolved. We can say confidently that man's capacity for language, abstract thinking, and rational foresight is the chief distinguishing mark that separates him from the anthropoid apes, the highest living specimens of the lower world, and that in general his innate psychic organization is more highly adaptable at birth. Moreover, man learns to a large extent through imitation and has a social consciousness, both of which powers his lower brothers apparently do not possess, though for some time it was generally thought that they did. But precisely what it implies neurologically and psychologically to be able to use language, think abstractly, pursue rational interests, and be endowed with a more flexible instinctive organization is by no means clear. The mental mechanism by virtue of which man is able to exercise his superior powers requires much more careful examination before his special capacities can be clearly differentiated from those he has in common with the rest of the animals. On the neural side, it is the task of comparative brain physiology to point out the convolutions and tissues that are to be considered of most significance in this connection and why.

The problem becomes if anything more perplexing as one turns from a review of progress in animal psychology to advances in our knowledge of the *savage* mind. Here, also, several misconceptions have been swept aside. Herbert Spencer left the impression which has been held till very recent times that the savage is, on the one hand, lacking in the common mental processes possessed by civilized man; that, like a child, he is "flighty, unstable, easily diverted, easily angered, easily amused, easily moved to wrath and malice," and that, on the other hand, he has at birth keener senses; that he can instinctively see farther, hear more

acutely, detect odors to better effect, and so on. In both these respects, modern research has shown Spencer to be wrong. There is no such disparity in innate psychological constitution between the average savage and the average civilized man as had been supposed.

Many savage children can be taught the ways of civilized children—and succeed in school—if started early enough. Many civilized men merely take on the veneer of civilization; they do not understand or master her ways; they think consistently very seldom, and for the most part go with the crowd. It is, in fact, confidently held on high authority that, *on the average,* civilized man has no better inherited equipment than has the savage, and that the chief difference lies on the cultural side, in the facility with which civilized man through the printed page and other scientific aids hands on his accumulated knowledge to succeeding generations.

There are, to be sure, gifted individuals in civilized races of a type not found among savages. These superior intellects perfect the technique of civilization. They develop the methods of science, art, and literature and devise the means of diffusing knowledge among the masses. But the highly gifted are few. They lead; the vast majority follow blindly, and so does the savage. The savage's leader is simply a lower type, and his cultural possessions are fewer.

The savage can no longer be regarded as a link that binds man to the lower animal kingdom. He is just as much a man as an American or a Frenchman is. He uses language, thinks, possesses foresight, and has the same flexible psychological mechanisms at birth. The most plausible theory to account for this similarity, in the light of our present knowledge that man—whether savage, barbarian, or civilized—has been on earth for many thousands of years, even hundreds of thousands, is that the lower form or forms

from which he sprang perished in the struggle for existence many generations ago, that man's instinctive nature has been definitely shaped in this long period of development, and that the savage is simply a human type, whose progress in comparatively recent times has been halted, left behind in the onward thrust of man's further evolution into civilization, yet nevertheless a man for a' that.

In connection with the last few paragraphs, modern *differential* or *variational* psychology tells an interesting supplementary story. Despite the Jacksonian dogma of the equality of all men, and the realization that the average savage and the average civilized man have much in common, there has been increasing evidence that men even in the same family are very unequal both in innate capacities and in dominating life purposes.

The rise of mental testing to evaluate individual ability has brought this fact home as never before. Following Francis Galton's pioneer work in England, the method was further developed in France and the United States, until to-day it is in wide and effective use, especially in industry and education. The most notable example of such evaluation of individual capacity occurred during the World War, when the United States applied its specially prepared intelligence tests to 1,700,000 recruits. The results were extremely significant. Less than one seventh (thirteen and one half per cent) proved to be of good intelligence, deserving a grade of A or B as measured by educational standards. About two thirds (sixty-one and one half per cent) exhibited passable intelligence, amounting to a grade of C. And one fourth (twenty-five per cent) were distinctly below the average. It must be remembered that this sample of a million and three quarters was more than representative of the entire population of the United States, since rejection for most obvious defects, mental and physical,

had already been made by the local draft boards. Whatever else these tests indicate—and authorities have already applied the findings to some of our social problems in a manner to give us pause—they at least demonstrate conclusively that there exists in the United States a wide variation in individual capacity on the intellectual side. There is, moreover, every reason to believe that the variation is as great if not greater on the emotional and volitional levels.

This cross-section of American intelligence is undoubtedly no different from that of any other highly developed community. Normal civilized man differs in his intellectual ability from the moron at the bottom to the exceptionally gifted at the top. So much is clear; as are also other matters of importance with regard to the inheritability of mental defects and superiorities. But the exact psychological and neurological significance of differing capacities is far from being worked out. Variational psychology is on the right road, but most of its journey is still ahead.

Turning to the last phase of our fourfold evolutionary approach to an understanding of the human ego, we find that in *child* study there is likewise much to be done before its contributions to the general subject can be rationally assessed. Nevertheless, work of considerable importance has been accomplished, especially in collaboration with men in the other fields of genetic study surveyed above.

In examining the psychological equipment of the adult, the question at once arises as to how much is native or hereditary and how much acquired or learned. Three broad classes of inherited traits, to follow the analysis of Professor Woodworth of Columbia, may be distinguished: instinctive reactions; deep-seated emotions; and native capacities. In the first class are to be included the psychological accompaniments, whatever they may be, of organic

functioning, use of sense organs, and motor responses, of "linking up certain movements to certain stimuli," such as food-getting, danger-avoiding, balance-maintaining, locomotion-producing combinations, of vocalizing reactions such as crying, cooing, and laughing, of exploratory movements with head, eyes, or hands, and of certain complex reactions occasioned by the presence of other persons, among them the sex, herding, and play tendencies. The inherited equipment of the second class is closely associated with that of the first. The emotions of fear, disgust, anger, grief, mirth, and lust are not acquired, and it is now well understood that, though their association with stimuli and reactions may be greatly modified by the learning process, there are certain organic secretions and bodily movements which always accompany them, such as flushing or paling, quickened heartbeat and breathing, acceleration or retardation of the flow of the stomach juices, the discharge into the blood stream of the secretions of the adrenal glands, and a general feeling of tension, relaxation, excitement, or impulse to act. In the third class fall the special aptitudes or gifts, such as a natural capacity for music, painting, mathematics, or oratory. These are undoubtedly hereditary, but they differ from the instincts of the first class in that no "ready-made reactions to stimuli" are provided. The native capacities involve both an interest in a specific field of activity and the ability to do well in that field. The equipment itself has to be acquired. Native capacities are as wide and varied as human interests, but, of course, only a very few at most are found in any one individual.

Formidable as appears the list of man's inherited instincts, emotions, and capacities, these are but a small proportion of the psychological organization each individual possesses upon reaching maturity. From the very moment

of birth, the child begins to modify its inherited equipment as a result of learning.

The process of acquiring knowledge proceeds, in the main, in three ways: by linking instinctive reactions to new stimuli; by compounding inherited reactions into more complex dispositions; and by separating instincts into more elementary modes for purposes of better integration with our dominant interests. It has just been said that the original stimuli and reactions associated with inherited emotions may be greatly modified by experience. This statement applies to the first method through which learning proceeds. We may instinctively fear the dark or the fur of animals, because of racial experience compacted into inherited equipment; but, if we are born into a civilized community, we learn that these fear reactions are valueless and attach our apprehensions to such things as automobile horns or burglars. Similarly with our other emotions. We adapt, condition, modify our inherited mechanisms to fit the society that receives us. In addition, we compound native tendencies into more complex forms, as in learning to speak, swim, or typewrite, or in blending the sex, protective, and esthetic impulses into a dominating love sentiment. Finally, we may break up instinctive reactions, such as flaring up in anger at an insulting remark, if experience teaches that in the circle in which we move such reactions are useless.

The foregoing distinction between native and acquired equipment is clear enough. But the differentiation in practice is not always easy, since some of our inherited dispositions do not appear or mature at birth. The biological law of recapitulation, seen to apply with such force in embryological development, finds its application on the psychological plane also, except that here it continues to operate for a long time after birth. The child in its unfoldment up to puberty and beyond is thought to retrace, however im-

perfectly, the psychic evolution of the race. Its long period of helplessness is but another name for the time needed to complete this recapitulation process. The sex instinct does not ripen till puberty, and in the interim considerable general knowledge has already been acquired. Other instincts ripen at an earlier, some at a later time. The chief problem in child psychology is to map out the precise order of their appearance or maturation so that in our educational efforts we may be guided accordingly. For education can but refine, perfect, and combine native dispositions, and it is folly to attempt to teach something for which the child in its psychic development is not yet prepared. The study of the original or inherited nature of man and of the order of its evolution from birth through adolescence is of highest importance. It has progressed as yet but little beyond the elementary stages. Animal, savage, differential, and child psychology are here combining to provide a more complete understanding.

§ 5

Among the various tributaries that enter into the broad stream of modern psychological advance there is, as we now see, much more than the speculative theorizing of half a century ago. Several main lines of progress are discernible: the Wundtian, which itself combines the contributions of the mental philosophers, the psychophysicists, and the physiological psychologists; the abnormal, which unites the study of deteriorated brain tissues accompanying incurable mental derangement with an investigation into the vagaries of the psychoneuroses; and the Darwinian, which comprehends the genetic study of animal, savage, variational, and child behavior. Since 1890 each of these lines has been energetically pursued not only for its own sake but

for the light it may throw upon an understanding of the general principles of psychology.

Wundt and his followers have discovered the exceedingly important law of psychophysical parallelism, have traced in detail the connection between many of man's conscious states and their respective neural accompaniments, have devised instruments for measuring the biological changes that go along with various states of consciousness, and have given us fairly adequate descriptive definitions of such states as sensation, perception, ideas, memory, imagination, reasoning, feeling-tone, emotion, attention, and will. Charcot and his disciples have established the importance of the subconscious, have pointed to the power of hypnosis as a method of psychological analysis, have demonstrated the relationship between normal psychic functioning and such derangements as hysteria and multiple personality, have opened up vast regions of latent psychic power, have begun an investigation into the functions of sleep and dreams, and have discovered that man has suppressed desires, subconscious drives, and conflicting interests which escape his conscious knowledge and control.

The accomplishments of the Darwinians, in attempting to arrive at an understanding of the fundamentals of origin and function in the life of the ego, cannot be summed up in a sentence. With respect to animal behavior it has been revealed that in psychological organization man is much more like the lower animals than had been supposed, that psychic factors probably determine the main course of evolution while changes in bodily structure are secondary, that consciousness and reasoning power (for a long time thought of as belonging to man only) are possessed by all higher vertebrates and possibly by lower forms also, and that the same kind of purposive activity exhibited by man is manifest

throughout the whole animal kingdom. This purposive activity, in which must be comprehended the main drives to human conduct, springs out of the blind impulse to live, to give full play to innate dispositions and capacities, and to reproduce one's kind. Human beings and other animals have inherited instincts and dispositions of great complexity: man's capacities for language, imitation, social consciousness, and for abstract thinking and rational foresight (rarely as these last two are exercised) mark him off from his lower brothers; although what man's superior capacities signify in terms of more complex neural and psychological mechanisms is by no means clear as yet. As between the average civilized man and the average savage, it has been found that there is little to choose in the matter of inherited psychological equipment; the chief difference lies in a cultural direction (in the facility with which the former hands on his accumulated knowledge to succeeding generations) and in the fact that a relatively few gifted individuals among civilized men are responsible for technical progress. The great variation in intellectual capacity among men, from the moron at the bottom to the genius at the top, has now been amply demonstrated. Finally, it has been established, man enters the world with his complex innate equipment of dispositions and capacities—as wide and varied as life itself—only partially matured; some of his drives and interests do not ripen till considerable acquired knowledge has been added. The chief problem here is to analyze the nature of these main drives, the order of their development from birth to maturity, and their relationship to acquired knowledge. Biologists have been endeavoring for more than a generation to find answer to the question: are acquired characteristics inheritable? To this a decisive reply must be received before some of our most pressing social problems, such as the possibility of improving back-

ward races, can be solved. The biologist cannot answer this question without the help of the psychologist, and especially without the aid of the student of animal, savage, and child behavior.

Despite the incomplete character of the results of the genetic approach, the evolutionary hypothesis has been well established in psychology. The will to live, to give rein to innate capacities, and to perpetuate one's kind seems to be the primal force behind all animal behavior, including that of man. It is seen expressing itself in the amœba as it moves blindly toward favorable or away from unfavorable environments. And as we go up the scale, the differentiation of function and development of nervous systems indicate how the ego has been groping upward and fashioning instruments for an increasing mastery over environment and for a fuller expression of its innate nature, which in man shows itself in many complex reflexes, instincts, dispositions, and capacities. The Darwinian foundation-stone of scientific psychology has been securely laid.

In other respects, however, one cannot speak with equal assurance. Turning to biology for an analogy, it will be remembered that the theory of evolution was not the only generalization which placed that study on a scientific basis. There were also the discovery of the embryonic germ-layers out of which the various body parts develop, and the enunciation of the cell theory together with the discovery of protoplasm. In short, two other generalizations besides the evolutionary hypothesis were necessary to transform biology into a science.

Psychology may not need as many or it may need more broad principles before it can be said to have come of age. At any rate, the application of Darwin's hypothesis, important and revolutionary as that has proved to be, is obviously not sufficient. What are the embryological "layers"

on the psychic side out of which the ego develops to full-grown maturity? Where is the "protoplasm" of the psyche?

Some psychologists have hailed *sensation* as the elemental stuff out of which the complex psychic life is formed. Others have insisted that simple *feeling-tone* is primary. A third group regard the image or *idea* as this elementary material. Still others look upon *volition* as in some way fundamental. An increasing number regard neither sensation, feeling-tone, idea, nor volition as elementary and think in terms of a vital force, as yet unrecognized by science, which through the ages has been pushing steadily upward from primeval chaos to natural law and order, and through these in turn by way of protoplasm and its myriad forms to man. In endeavoring to arrive at elementals, psychologists are still far from being of one mind. Despite the efforts of William James to build up a harmonious system, many divergent schools of psychology hold the field to-day—introspective, physiological, genetic, purposive, psychoanalytic, behavioristic, "gestaltic"—each contributing data of importance, but each too often claiming that its way is the only way to the truth.

Probably the facts upon which an agreement can be reached as to the fundamental elements of the psyche are still to be discovered. Possibly "histological" and "embryological" studies of the ego are to come. The Baer, the Schwann, and the Schultze of psychological research have apparently not yet appeared. Until they do and the elementals of the psyche have been discovered or are generally recognized, the youngest member of the scientific family cannot be said to have reached her majority. She must look for still further assistance from the brain physiologists for the neural facts upon which she builds, but in the interim there is still much that the study of origins and of the subconscious can reveal. The seventh Seal of Science

is apparently not yet completely broken, although much of importance has been discovered, and students are unquestionably pushing forward in the right direction.

§ 6

We have now completed our survey of how the greater men of science successfully grappled with the problems contained in Nature's Book, and we have scrutinized its pages in some detail. Our purpose has been threefold: to secure a fairly comprehensive idea, a bird's-eye view, of what the Book of Nature reveals; to familiarize ourselves with the methods used by the leaders of thought who broke through the barriers of ignorance and inherited misconception to penetrate nature's secrets; and to trace the sequence of the unfolding of the sciences. A definite chronological order is disclosed. Mathematics was developed as a tool of thought and scientific generalization before constructive advances were made in physics, chemistry, and astronomy; physics preceded chemistry, and both of these were developed further before additional progress in astronomy was forthcoming, and before geology and biology began to secure a scientific footing; portions of astronomy are fundamental to geology, and of geology to biology, and psychology did not extricate herself from the wilderness of metaphysical speculation until biology was far enough advanced to provide an accurate picture of the structure and functioning of the sense organs, brain, spinal cord, and the remainder of the nervous system. The Book of Nature now lies almost completely open before us. Man is finally in possession of the necessary scientific information. Once he rids himself of certain remaining prejudices and misconceptions, he can begin to fashion a scientific social order.

To say, however, that the Book of Nature lies almost completely open before us does not imply that we as yet

fully comprehend its pages. Some of the record is still difficult to decipher, and, although man has already benefited much by his study of it, the most important mysteries have not been unraveled.

Undoubtedly the most difficult problem for many students is to reconcile the seeming discontinuities or contradictions (often called dualisms), which occur at various points in nature, with the evident unity which maintains for the most part and which has received its strongest support in the theory of evolution. The problem expresses itself in the concepts of matter versus energy, of the inorganic versus the organic, of determinism versus free will, of living matter versus the psyche—not to mention those questions which still lie beyond the scope of scientific inquiry, such as our religious perplexities, but which at any moment, as science progresses, may be brought within. Yesterday questions of space and time were deemed too metaphysical for science. To-day Einstein's theories have made them part of everyday scientific thinking; and to-morrow, with further extensions of knowledge, there is no prophesying what others science will be forced to consider.

None, however, of these examples of apparent duality in nature is necessarily irreconcilable. In the light of present knowledge of radioactivity, electronic behavior, and penetrative rays of energy, matter can hardly be any longer regarded as either "dead" or "solid," nor energy as "immaterial." Energy is produced by matter and is always associated with motion. The only remaining problem here is whether the motion is of material particles projected by matter, or whether a surrounding medium, such as the ether, plays the dominant rôle. But in either event there is no longer an impassable gulf fixed between matter and energy. There is no discontinuity or dualism here. One directly affects and is affected by the other.

As for the seeming discontinuity that once completely separated the inorganic from the organic realm, recent investigations have again tended toward a unification. In their characteristic manifestations there are real differences between the two, but on the border-line these differences now blend into resemblances until the distinctions become almost completely obliterated. The question here has resolved itself into discovering how living matter originally emerged from the non-living, but this assumes that the gap can ultimately be closed and that no real discontinuity exists at this point.

Possibly the most characteristic distinguishing mark between the inorganic and the organic is the seemingly "determined" activity of the one and the "freer" behavior of the other. Many modern scientists have made short shrift of this distinction by simply denying that "free will" exists at all. There can be no question that the older conception of freedom is taboo among scientists to-day, especially the interpretation which presupposes a moral duality (between God and devil) and man's alleged ability to choose between the promptings of two opposing forces. But the denial of this theological dogma does not solve the problem of organic "freedom" as opposed to inorganic "determinism." Those who dismiss it peremptorily reckon neither with the exceedingly important fact of variation nor with the equally important psychological fact of human striving toward an ideal. If there is an essential Unity behind all things, variation and freedom must be included in it; and one need not view that Unity as static or completely unfolded. A dynamic conception, in which the Unity is thought of as continuing to unfold, experiment, strive, and in which variation, evolution, and freedom are thus readily comprehended, does much to clarify the problem of "freedom of will"—the obvious ability of higher organisms, within the limits set

by heredity and environment, to choose between alternatives.

But the seeming contradiction between organic freedom and inorganic determinism still remains, unless we turn to the Kantian distinction between the *phenomenal* and *noumenal* worlds for a further answer. Unless the revelations of Galileo and Newton regarding the meaning of sound and light and other sensations are fully grasped and it is appreciated that the only aspects of ultimate reality which the non-mental sciences bring to us are *appearances* only, no solution is forthcoming. But once the distinction is comprehended, an answer is found. Determinism attaches itself to the appearances of things, to the phenomenal aspects of reality. We experience freedom only in human consciousness, which is not phenomenal; we may assume that it is a part of the noumenon, the *Ding an sich,* the objective reality, which the non-mental sciences can never reach except through the mediation of the senses. Determinism and free will, therefore, may simply pertain to two sides of the same shield, or, better, to the "outside" and the "inside" of the same Reality.

In this thought, also, lies the possible reconciliation or unification of the apparent discontinuity existing between mind and matter, the noumenal world of the psyche and the phenomenal world of appearances. But if mind and matter are thought to represent the "inside" and the "outside" of the unitary Reality, then to be logical we must extend the idea of psychic existence not only to organisms possessing nervous systems but to all organic matter and to the inorganic realm also. The psychic activity, the ego, of man then becomes simply the "upper end" of the noumenal world itself. So viewed, at any rate, the seeming dualism of mind versus matter is resolved into a unitary Reality.

The exposition of the last two paragraphs is, of course, in the main speculative. It still pertains more to philosophy and metaphysics than to science. But it at least serves to suggest that none of the seeming dualities or contradictions in nature is necessarily unresolvable. We may legitimately maintain a faith in the unity of all things, but in our scientific procedure we must be careful to be guided wholly by the facts in formulating workable hypotheses, no matter how contradictory such hypotheses may at the time appear.

This reasoning applies, also, to one other apparent contradiction—that which sets the natural sciences over against the social studies and is comprehended in our figure of speech contrasting the Book of Nature with the Book of Society. In nature are found fixed laws; in society, it is maintained in this essay, there is as yet no evidence of such fixity or inevitability. Here the seeming contradiction or discontinuity is resolved in the conception that a cosmic experimentation has been in process since primordial time, and through the development from amœba to man, and that it has for the most part crystallized itself into set ways (we call them laws of nature) in the millions upon millions of years of its duration, so that in retrospect we can readily observe the results of the process; the fact of mutations is evidence enough that experimentation in the cosmic sense and in the "natural" realm is still going on. Alongside of this result may be laid the experimentation of man, who, as part of the cosmic process, has for only a few thousand years been endeavoring to fashion a society. His experimentation has by no means as yet crystallized itself into set ways. Possibly ten million years hence a higher form of organism, a superman perhaps, will look back and see fixed laws in society. At present, however, the social order is most decidedly undefined. It lies very largely within the

power of man's intelligent direction to "determine" what the laws of society shall ultimately be. So viewed, at least, the seeming discontinuity between the Book of Nature and the Book of Society disappears.

CHAPTER XIV

SOCIAL SCIENCE IN THE MAKING

§ 1

HERE and there in preceding pages, and especially at the beginning of the book, the marked contrast between rapid material advance on the one hand and halting social progress on the other has been pointed to. In Chapters IX and X it was shown that this discrepant situation exists to-day even more vividly than at any previous time in history because of the phenomenal metamorphosis in man's control over nature brought about by the mechanical and chemical revolutions at the same time that he was continuing to show himself a colossal blunderer in the realm of social affairs.

There are, it is true, some bright spots in nineteenth-century history which have not yet been indicated, such as a rapid rise in the standard of living, the abolition of slavery in America, the more complete establishment of nationalism, the diffusion of popular education, and the extension of democratic government. But it is very questionable whether these and other evidences of social progress—surprising as this assertion must seem to many people—have been due to any other factor than the achievements of natural science.

The influence of recent physical advance upon industry and government has been explained in Chapter IX. A few additional words will serve to indicate its effect upon the social developments to which reference has just been made. It has, for instance, been the introduction of power-driven machinery which has lowered costs, raised the standard of

living, and provided more leisure for millions of workers. To-day some machines do the work of ten thousand horses and accomplish more than an army of slaves. As a result the character of human labor has been transformed. In early times most men labored at purely routine drudgery. Hence the need for slaves and serfs. With the coming of machine power, human slavery ceased to be necessary, and those who direct industry came to realize that the machine operator must be literate; he must be able to read instructions. The rapid advance of popular education in industrial countries in the last seventy-five years is to be accounted for more on this score than on any other, although, of course, the economic cause is by no means the only one. And with popular education has come a desire on the part of the masses for greater participation in government.

The development of the railroad, steamship, cable, and telegraph brought people the world over immeasurably closer together and made it possible for the spirit of nationality to assume wider scope. In the motion-picture spectacle, "The Birth of a Nation," the people of the United States are pictured as not having become thoroughly unified until after 1863. This is undoubtedly true. Before the days of the railroad and the telegraph, distances in America were too great for people effectively to communicate with one another and to become united in patriotic spirit. And what is true of nationalism in America has been true, though possibly in lesser degree, in other countries.

Similar is the scramble for overseas possessions. Again the development of the steamship, railroad, cable, and telegraph made this possible, especially in the conquest of Asia and Africa by Europeans. The British colonial empire consisted only of coast-line settlements in North and South America, Africa, and Asia, until the British East India Company with its steamships prepared the way for direct

imperialistic expansion. Later Germany, France, and Italy by means of similar methods of transport took part in the scramble. In 1850 Africa was a vast unexplored region with a few colonial settlements dotted here and there along the coast. By the end of the century, as a result of rapid steamship and telegraphic communications, and of the application of medical and engineering science to make possible the occupation of tropical regions, the interior had been generally explored, and its division among seven European countries was practically complete. If there is a somewhat different story to tell with respect to Asia, it is because Japan and the United States refused to allow the same partitioning process by European nations to occur there.

It is quite apparent from these and other illustrations which might be given that nineteenth-century changes for the better in the structure of society have been due very largely to advances in physical science. Modern astronomy, geology, biology, and psychology have also had their effect upon social progress, but as yet this effect has been insignificant compared with that produced by mathematics, physics, and chemistry. The application to the uses of mankind of a few decades of steam power, electrical energy, gasoline combustion, chemical analysis and synthesis, has brought about a greater metamorphosis in man's habits of living than all previous ages of warfare and political scheming had been able to achieve.

At the same time, however, advances in the material realm have been by no means an unmixed blessing in their influence upon social change. Many of the older evils have simply given way to more pernicious ones; others have been considerably complicated by increased material prosperity; and still others remain unsolved, despite biological and psychological advance, because of the superstitions and prejudices that continue to surround them.

With nationalism has come arrogant imperialism. Democracy has brought with it widespread corruption and inefficiency. While the mechanical and chemical revolutions were affecting the social structure in unprecedented fashion, kings and princes were continuing their medieval proceedings, slicing up Europe to suit their whims, and preparing the world for the catastrophe of 1914. And now Soviet Russia and Fascist Italy raise the flag of revolt against some of our most cherished political ideals. Mussolini contends that the democracy of the United States is more apparent than real, that rich nations which can afford to do so may properly waste some of their riches in inefficiency and the spoils system, and that liberty is an outworn dogma, "more or less decomposed." Some of America's industrial leaders agree in large part with the Italian Duce, maintaining that Italy under Mussolini is a step ahead of Republican France. Mussolini, Lenin, and these industrialists may be entirely wrong, but democracy and republicanism are certainly at the cross-roads. Unless, as Robinson suggests, we stop appealing "to policies of a century back . . . now become a warning rather than a guide," and apply the lessons of modern science to governmental advance, we may expect a tremendous upheaval politically if the propaganda of Lenin, Mussolini, and the industrialists is allowed to prevail.

The obvious answer to the shortcomings of present-day democracy is, of course, that in a prosperous nation like the United States, where the people are well fed, well housed, well clothed, and have some margin left over for the less material comforts, political difficulties can safely be condoned. Economic soundness, it is maintained, is the essential matter. But quite apart from the fact that our industrial prosperity is due in the main to advances in physical science and not to the social philosophers, are we so very sound economically after all? What about methods

of corporate organization and stock control which interfere with the rights of stockholders and which Professor Ripley of Harvard has been attacking, the closer and closer concentration of wealth in the hands of a few, the rise of an ostentatious leisure class, the marked tendency toward monopolistic control of industry, and the inability of constituted political machinery to cope with the huge super-units of corporate enterprise that have been developing? Professor George A. Coe of Columbia indicts certain characteristics of our present economic order in the following words:

> . . . It is not necessary to press the point that the industrial system breeds manifest and manifold injustice; a glance at the motives that are assumed and stimulated is sufficient. The characteristic motives—not the only ones, but the ones toward which the system as such gravitates—are obviously as follows:
>
> (a) In the organization and use of capital it is taken for granted that the dominant purpose will not be the glory of God (however this be understood), nor the improvement of human life (one's own or others), nor supplying the wants of men, but accumulation of profits and of power for the enjoyment of the possessor and his family.
>
> (b) It is currently assumed that among the employing classes the dominant motive is to get the most possible for the least return.
>
> (c) Since conflict is of the essence of industrialism, an essentially pugnacious self-interest is assumed to be fundamental in human nature.
>
> (d) Insincerity permeates the whole, for every partisan interest endeavors to pose as a promoter of the public or common welfare.

The United States is at present relatively secure against socialistic and communistic propaganda because the pressure of population upon the means of subsistence has not yet (as it has in Europe) brought our social inequalities to the fore. It will not be long at the present rate of increase before our population problems become serious. When that day dawns in America, unless some of the most flagrant industrial ills

have in the interim been mitigated, the red flag may wave as violently here as it is now waving elsewhere.

Population problems the world over are becoming every year more menacing. Italy, Germany, Japan, and other countries are already confronted with most harassing overpopulation. The United States will probably face a similar situation in from half to three quarters of a century. (Millions now living in this land of freedom and opportunity will see that day.) American discussion and restriction of immigration since the World War, which itself summarily removed some eight million souls, bear ample witness that our day of population pressure is not far off. A German authority, Professor Penck, estimates the present population of the earth at 1,800,000,000, the maximum it is possible to support at from eight to nine thousand millions, and the period within which this maximum will be reached in temperate zones at less than a hundred and fifty years. The whole earth, at the present rate of increase, may be overpopulated in three hundred years. Contrary to general belief, the white race is multiplying at a higher rate than the yellow race, its only real competitor. At the same time, civilization is burdening itself more and more with its unfit, and science is constantly lengthening the average span of life. On the basis of recent medical advances, babies born in the year 2000 will have an expectation of life of more than one hundred years, says Professor Hornell Hart of Bryn Mawr, and some of them will probably live to be two hundred years old. Unless there is widespread resort to birth-control, the earth is moving headlong toward further disaster because of increase of population.

Other menacing social questions are the advancing divorce rate, the delay of marriage to a relatively late age, and increased freedom of sex relations outside of wedlock on the part of both women and men; prostitution,

venereal disease, abortion, and illegitimacy; breakdown of parental control over children; and an alarming increase of youthful criminals. There is no bigger field of prejudice and misguided effort at reform than with respect to these problems. They are among the most serious; and yet how many people can face proposed remedies—as voluntary limitation of offspring, sterilization of the unfit, compulsory report by physicians of cases of venereal disease, marriage health certificates, easy divorce where the parties are evidently mismated and no issue has ensued (quite apart from questions of infidelity and adultery)—how many can face these and similar proposals of reform sanely and dispassionately and without allowing irrelevant prejudices to dominate their reactions?

Modern biology and psychology have already provided a sufficient body of facts for the fashioning of constructive remedies in these matters, but too many misconceptions hold the field for the remedies to be effectively applied. The early church developed the absurd dogma that man is "born in sin and iniquity" and frowned upon sexual intercourse. The result was that an imperious instinct, looked upon with suspicion even in wedlock, found increased expression in sordid and covert ways. Prostitution reared its head still higher to mock the institution of marriage and created an ever more serious social problem in venereal disease and debauchery. To this day the sex instinct, which should have been made pure and holy above all things, whose expression between mate and mate ought to have been synonymous with the highest and best of spiritual exaltation and communion, has been kept degraded. Parents have literally begotten their children in sin and iniquity so far as their inverted conceptions of the process has been concerned; woman has until recently been kept in repressive ignorance; and the husband, who by all good standards has been

granted the man's exclusive privilege of sowing "wild oats" (and incidentally reaping venereal disease), has brought to the nuptial night memories and habits of the brothel to outrage the sensibilities of one who has lived her sex life largely in the fairy-tale configurations of her imagination. Increasing divorce and the tendency of modern femininism to ape the vices of man should ere long bring humanity to its senses in matters of sex, though the most apparent result thus far has been to confirm the church in its medievalism. There is nothing more preposterous to-day, from the standpoint of science, than the dogma that the operation of the sex instinct is sinful and iniquitous. Society should, of course, continue to circumscribe its expression for the protection of offspring and in the interests of a sound morality, but this is another question entirely. A proper scientific attitude toward our fundamental instincts is necessary before constructive social control of their expression can be assured.

The instruments of last resort in social control are law and law enforcement. It is common knowledge that these have virtually broken down in recent years and that crime and disrespect for law are increasing at an alarming rate. Crime is a standing challenge to any social order. Where it is on the increase something is radically wrong, either in the laws themselves or in the administration of justice or in both respects. As for our enforcement machinery, it is enough to repeat the findings of the National Crime Commission that ninety per cent of the major lawbreakers remain at large, that seventy-five per cent of those that are caught escape punishment, and that "the trial of the criminal has become a game of skill, cunning, and endurance between opposing lawyers" rather than an impartial effort to establish guilt or innocence. With respect to these problems, Dean Roscoe Pound, of the Harvard Law School, recently said:

> The whole machinery for maintaining law and order, the facilities for the detection, prosecution and adjudication of criminals and their penal treatment, not only antedates the motor vehicle but functions from a rural and agricultural viewpoint. That is the machinery which is expected to cope with the problems of a heterogeneous population in the great cities, where there is all possibility for crime, for escape and congested court calendars. . . .
>
> There are grave defects in the administration of justice in all American cities and it is our duty to lay broad and deep the foundation of what we decide to do in the day of reform that is to come.

But it is not only the administration of justice that is at fault; it is in many instances the laws themselves. If legislation runs counter to deep-seated dispositions, or if social conditions are such that the primal instincts are thwarted in expression, law enforcement is impossible even with the most efficient machinery. Many laws on our statute-books run counter to human nature. They have been enacted either in total ignorance of natural laws, in deliberate disregard of them, or because preconceived sectarian prejudice or vested interests have dictated their passage. What is needed for the better formulation of law, to quote Dean Pound again, is "careful, continuous, scientific research for the underlying conditions, for the limits and scope of the problems, for the materials available for solutions." These conditions, limits, and materials can be understood only in the light of biological and psychological principles.

And what shall one say about twentieth-century religion and morality? Here indeed is confusion worse confounded. The kaleidoscopic events of the last few years, such as the rise of the Ku Klux Klan and its extralegal practices, the heresy trial of Bishop William M. Brown and the subsequent rush after his conviction to hear him preach, the continued complaint on the pope's part that modern governments are less and less amenable to his control, the

mock trial of young Scopes in Tennessee, the attempted persecution of preachers like Harry Emerson Fosdick, the noisy struggle between so-called Fundamentalists and Modernists, the rapid spread of fantastic and barbarian religious cults in the midst of a vaunted Christian civilization, the stripping off of the veneer of that civilization in the greatest and most barbaric holocaust of all time, with the song of hate replacing the spirit of brotherly love among Christian peoples—what can one say of such a situation except that religious values are quite evidently in the melting-pot? The younger generation, furthermore, is in revolt against many of the medieval shams and hypocrisies still too prevalent. The danger lies in the risk that the swing of the pendulum will go too far the other way. Already unspeakable sex orgies have been uncovered among school-children. The New York City Board of Education after a recent protracted study of morals in its schools finds that a very definite scheme of moral instruction is necessary to combat the prevailing low standards and evils. Is it any wonder that many sincerely religious though unorthodox people are turning to science in their extremity, hoping that before long it will be able to reach out beyond the material side of experience into the mental and spiritual realms and establish substantial guide-posts for man's moral gropings and bewildered longings?

Whether we turn to problems of government, economics, population, the family, law and the administration of justice, morals, or religion, there is little choice as to which are the worst confused or most depressing. Modern physical science has helped social progress somewhat, but where some evils have disappeared other more complicated questions have arisen, and the major social problems have in the main been left untouched.

§ 2

For thousands of years brute force and intrigue have been the dominating factors in human affairs. It is only in recent centuries that science has been able to make any substantial inroads upon them. This fact has doubtless already become fairly apparent to the reader. Its significance stands forth even more conspicuously as the historical development of politics, economics, jurisprudence, and ethics is passed in review. These fields present themselves retrospectively both as objects of speculative theorizing and as the records of actual social changes that have occurred from time to time.

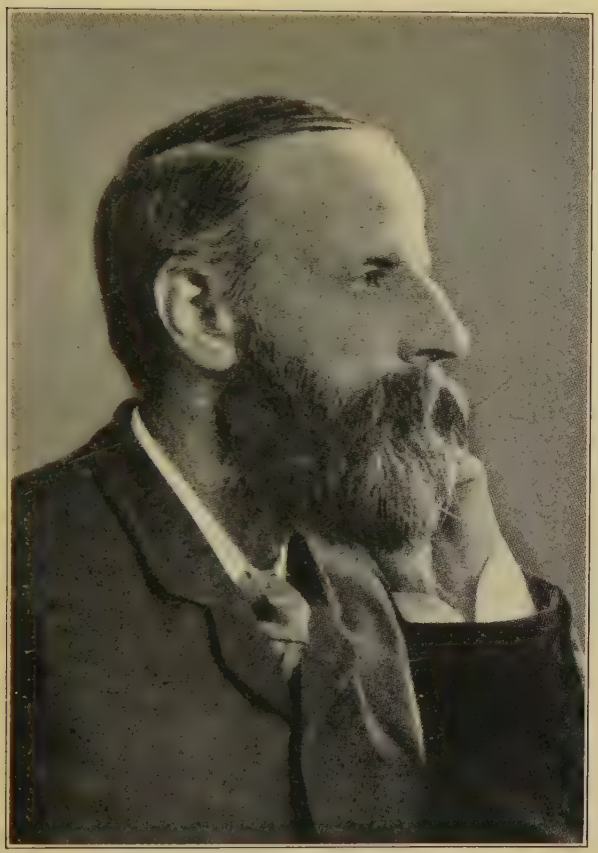
The social studies, like other conjectural ventures of the human intellect, saw their first rational development in ancient Greece. Plato and Aristotle are the outstanding leaders here as elsewhere. In fact, Plato's "Republic" and Aristotle's "Politics," along with other notable books which they and the Stoics, Epicureans, and Sophists wrote, constitute a series of analyses of man's social relations that have not been surpassed to this day. They are admirably presented in a recent book by Will Durant, "The Story of Philosophy," which should be consulted for details. We have built upon the Greek ideas regarding natural science and have advanced immeasurably there; but, as will become evident presently, we do not as yet face our social problems with the same candor and fearlessness with which, after the purging administered by the Sophists, the Hellenes faced theirs. We are haunted and enchained by taboos and prejudices from which Socrates, Plato, and Aristotle had freed themselves. The evil eye of the Dark Ages is to a large extent still upon us.

Between the seventh and the fifth centuries B.C., Greece experienced important social changes which stirred up much

speculation. The Hellenic city-state was by this time already highly developed, having passed through the monarchical, aristocratic, and despotic forms, and having settled down here and there to a democracy of the citizens. The community was complexly organized; a superior level of civilization and culture had been attained; an economic division of labor, some banking facilities, and an active foreign trade were in existence; and there was a marked social and political consciousness. Because of the institution of slavery, citizens were freed from laborious drudgery and could devote themselves to self-development. They lived in close association. They met daily in the market-place or in the theater, and found considerable opportunity to work together.

The Greek thinkers recognized the existence of such broad categories as politics, economics, jurisprudence, and ethics in social activity and insisted that these fields must be viewed as interrelated, since one cannot be understood apart from the others. Plato and Aristotle thought of society as an organic whole. Plato went so far as to suggest a communism of property and women to eliminate rivalry and friction, while Aristotle felt that such innovations would only cause more difficulty and made a masterly analysis of the bearing of filial affection and family life upon the welfare of the community. Modern sociologists are now taking a similar position regarding the essential unity of social activities, and so are the most progressive of our publicists, economists, jurists, and moralists; but for many centuries after the Hellenic period these fields were viewed as quite separate from one another, and they are still so viewed by many specialists to-day.

Ethical considerations were paramount in all the social theorizing of the Greeks. They were aiming at the highest good of the citizens, and they thought of society as subject to man's control and design. And by ethics they meant



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neither slavish adherence to customary morality on the one hand nor to current religious dogmas on the other. They endeavored to establish a satisfactory philosophy of social living, to understand the needs and potentialities of human nature. The Greeks were, of course, wide of the mark in much of their moralizing. Even now our knowledge of psychology is so meager that scientific ethical standards are as yet beyond our ken. But the ancient thinkers had at least freed themselves from conventional morality and superstitious fantasy, which is more than can be said for many of us moderns. Out of their speculations regarding goodness, justice, virtue, right, duty, and the like have come most of the ethical concepts which at one time or another since their day have dominated ethical theorizing—conceptions such as the alleged ability of all intelligent men instinctively to tell right from wrong, the idea of a spontaneous discernment of what constitutes the ideal life, the dogma that one man's good is every man's good or that personal pleasure and happiness are the sole criteria of ethical value, the advocacy of the simple life as against the pleasures of the world, and the belief that whatever is is right and that calamity should therefore be faced without complaint.

Some of these conceptions modern biology and psychology have demonstrated to be superficial or inadequate as well rounded ethical guides; others, to be wholly fallacious. But whatever their value, they are not, as is commonly believed, of modern origin; they come down to us from the ancients.

Most of the contributions of the Greeks in other fields of social study centered around the nature of the state. Legal theories were tied up with their ethical speculations; they observed the great diversity between the customs and laws of the Hellenes and those of the barbarians, and between the Greek cities themselves, and endeavored to

find a better basis for social control than the traditions or legislative decrees of whoever happened to be in power at the moment. As for their conception of economics it was inseparably associated with their ideas of politics and jurisprudence. In the ideal commonwealths of Plato and Aristotle workaday activities were interwoven with political and other social activities.

With the help of the hundreds of scholarly assistants placed at his disposal by Alexander the Great, Aristotle was enabled to make an exhaustive analysis of the constitutions of more than one hundred and fifty Greek city-states, to discuss intelligently the conditions under which tyranny, monarchy, democracy, and other forms of government are most likely to thrive, and to indicate in what respect personal and economic factors foment discord, corruption, and revolution. Aristotle's observations and generalizations in these matters are among those ancient achievements which have not to this day been improved upon.

Other theories of the Greeks that had their influence either in changing or in justifying subsequent social conditions were the conceptions of government providing security for person and property, of citizenship based on intelligence and virtue (we now count noses instead), of the principle of proportional representation, of the brotherhood of all men (striking at the custom of slavery which both Plato and Aristotle justified), and of the state as based upon a form of "social contract" or as the expression of "natural law." Some of these ideas, dogmatically accepted after the Dark Ages, are still embedded in our prejudices, as are others brought in by Christian, barbarian, and subsequent influences. The touchstone of natural science and impartial observation is still to be completely applied to them, to distinguish the true from the false.

What happened after the Greek city-states were swal-

lowed up in the Roman Empire has already been outlined in detail in preceding pages. Freedom of thought was completely suppressed after Constantine and the rise of intolerant Christianity, and it is not until the period of the scientific renaissance that an attempt is made once more to get back to the independence and democratic institutions fostered by the ancients. This social emancipation, this return to the ways of the free Greek citizens, modern civilization is still in the process of achieving.

The Roman Empire had developed a system of law, administration, and government to suit its own purposes. This system dominated medieval conceptions of politics and was used as the model in the establishment of the Catholic Church. The dogma of human law as in some way synonymous with "natural" or "divine" law was fully utilized to secure unquestioning obedience to the fiat of emperor, king, or pope. Capricious mandates were thus readily lifted to the plane of inexorability, and the legal doctrine fostered by this wholly mistaken analogy drawn from natural phenomena has also come down to modern times.

With the fall of the empire, early Christian dogmas came into the ascendancy. These were a fusion of various ideas derived from the sayings of Jesus, the interpretations of Paul, the Apostles, and the Church Fathers, the religion of the Jews, the philosophy of the Greeks, the legal concepts of the Romans, and the myths and customs of the Teutonic barbarians. The important contribution of Christianity to social philosophy consisted in giving universality to the idea of brotherly love, but this has never been dominant even to this day, a thick husk of ritual hiding it and an Oriental plan of salvation infusing it. With the passing of the empire, life on earth came to be regarded as wholly preparatory to a life hereafter, and social activity was subordinated to a future reward. Jurisprudence, politics, eco-

nomics, and ethics became branches of theology, and thus they remained for centuries.

Rome had developed city life and commercial activity, whereas the Germanic races emphasized agriculture and neglected trade. Early Christianity led to a number of unsuccessful communistic experiments. Later the church decided that communism was an ideal made unattainable by the "fall of man" and approved individualistic enterprise. From the sixth century, the struggle between pope and emperor becomes the outstanding political phenomenon. Each draws his arguments from Scripture and represents himself as divinely ordained. Socially, the feudal state takes on increasing importance.

The Crusades helped break the trade barriers that had developed after the fall of Rome and created a demand for foreign goods which resulted in a revival of commerce and industry. National states now come into being. A middle class of artisans and merchants arise and become influential, and here and there free cities are again established. The feudal nobility begins to feel the power of the supreme authorities. Finally we see during this period five conflicting elements struggling for supremacy: emperor, pope, king, free city, and feudal baron. At the same time so much of Greek philosophy and Roman law as is pleasing to the church is revived and taught in the Italian universities, and a new period of social theorizing begins. Attempts are made to revive the study of Roman law for the purpose of justifying the claims of the emperors; formal logic and scholastic philosophy are utilized to compile stereotyped legal commentaries and glossaries; divine authority and the obligations of people to their rulers and priests are stressed.

All this is harmless until such scientific devices as the mariner's compass, the printing-press, and gunpowder, together with the scientific questionings stirred up by Roger

Bacon and carried into practical effect by Vinci, Copernicus, Cordus, and Vesalius, disclose a new world, foster exploration and colonization, and break the grip of ecclesiastical authority. Greek writings are now more earnestly searched for better social theories, and the most important effect is an airing of ideas about popular sovereignty, the "right" of a people to depose a ruler, and the possibility of constitutional restraints upon the absolute power, both ecclesiastical and secular. At the same time Machiavelli's notable (or possibly one should say notorious) work, "The Prince," marks the culmination of the political struggle between church and state. In it a supreme note of unfettered secularism is struck—the unmoral spirit of absolute sovereignty which, though divorcing the state from papal influences, was to create international difficulties down to our own time. Somewhat later, Bodin also wrote an important work, emphasizing the claims of the national state.

The Protestant Reformation and the Catholic Counter-Reformation, headed by Luther and Calvin on the one hand and by the Jesuits on the other, likewise occurred about this time. Although both these movements were opposed to the scientific awakening which constituted the most important event of fifteenth and sixteenth century history, they nevertheless between them gave emphasis to the spirit of revolt and free criticism, the movement toward individualism and popular sovereignty, and the resurrection of the later Greek dogmas of natural social laws readily discernible, an original state of nature in which man was thought to have lived like an unsocial animal, and a social compact through which society was supposed to have been organized—dogmas of extreme influence in subsequent advance but now known to have no foundation in biological and psychological facts. If there are natural social laws they are not written in the sky where every one may read. They

must be ascertained as any other scientific generalization is ascertained, by observation and experiment, and, being social in nature, they must await the establishment of certain foundation facts of biology and psychology. As for an original unsocial state of nature and a social compact, these catch-phrases served their purpose in combating prevailing despotisms, but they have just as little foundation in fact as have the ideas of the divine right of kings or the infallibility of the pope. The sooner now that the world is rid of all these misapprehensions, the better will it be for social advance.

At any rate, by 1600, when Bruno's body was consigned to the flames in a last desperate effort to stem the rising tide of independent thought, enough of these later Greek social speculations had been revived so that it was merely a question of further emphasis and elaboration before the world was ready for the English Revolution of 1688, the American Revolution of 1776, and the French Revolution of 1789. Absolute monarchy had unified the national state, had established the king in power, and had secured the state's independence of external control of pope and emperor and its supremacy over all internal groups, civic and feudal. At the same time a movement had taken shape favoring limited monarchy based on constitutional forms and full democracy with popular sovereignty.

Among the leaders in this political reform may be mentioned Althusius and Grotius (one viewing the state as an association of lesser communities, and the other founding international law on the theory that a kind of "natural law" governs the relations between nations), Locke (who supported the English Revolution against the arguments of his fellow-countryman Hobbes, and whose ideas regarding the individual's rights to life, liberty, property, and freedom in religious worship have been so instrumental in sub-

sequent political changes), Spinoza, Leibnitz, Berkeley, Hume, and Kant (whose philosophic speculations had a marked influence on all the social thinking of the time), and Montesquieu, Voltaire, and Rousseau (whose writings had much to do with bringing about the French Revolution and with the framing of the Constitution of the United States). The works of most of these powerful and stimulating writers are well known and can be passed over without detailed comment. Taking their arguments from the later Greek speculations on the one hand, and from the scientific discoveries and pronouncements of Gilbert, Kepler, Galileo, Francis Bacon, Descartes, Boyle, Huygens, and Newton on the other, the social philosophers of the seventeenth and eighteenth centuries laid the basis for a return to Greek freedom and democracy in the affairs of government.

Geographical exploration and scientific discovery also had a decided effect upon industry and economics. The shift of commercial activity from the Mediterranean to the Atlantic gave a great impetus to capitalistic enterprise and ushered in the so-called policy of mercantilism which was maintained in force for three centuries, until the period of the American Revolution. The object of this policy was to strengthen the national state and protect it from rivals by using military and diplomatic power in the furtherance of commercial interests. One after another, Portugal, Spain, Holland, France, and England, through navigation acts, trade restrictions, high tariffs, and open warfare, endeavored to secure the advantage and establish great colonial empires in the Americas.

At the same time that mercantilism was strengthening nationalism, the new spirit of invention had led to important improvements in the English cotton industry which gave the needed impetus to the Industrial Revolution and

occasioned the rise of a powerful manufacturing class. This class now began to resent the restrictions imposed by the state upon their activities, and, since by this time monarchy had been considerably weakened in England, they were bold there in demanding a change. In this they were aided by the doctrines of the so-called physiocrats, in France, who held that inexorable laws operate in the social realm, that individual interests coincide with group interests, and that it is best for society in the long run to give people the opportunity to work out their own salvation without governmental interference (the dogma of *laissez-faire*). We now know that this unalloyed doctrine does not bring the social benefits claimed for it, but it served its purpose in combating mercantilism and in securing individual freedom in economic affairs. Out of it arose the ideas of free competition, free labor, and free trade within the nation, which ultimately passed from speculation to practical application in every industrial nation.

In 1776 appeared the first notable book on economics, "The Wealth of Nations," by the Scotch moralist Adam Smith (1723-1790). Building on the suppositions of the physiocrats, though reinterpreted along Bacon-Hume lines and considerably modified in application, Smith developed a consistent body of doctrines and established what is known to-day as the classical school of economics. Together with the powerful arguments of the manufacturers of England this book put an end to mercantilism in that country, substituting in its place a thoroughgoing and inhuman *laissez-faire*—every man for himself, and the devil take the hindmost. Other countries soon followed the example set by England. It was not then realized that the new doctrine, if applied logically in all spheres of social activity—governmental, legal, and ethical, as well as economic—must inevitably lead to pure and unadulterated anarchism.

Two eminent followers of Smith elaborated his work. Malthus, a young clergyman, wrote an epoch-making essay in 1798 which indicated that population tends to outstrip the means of subsistence, and that wages under *laissez-faire* must sink to the minimum of existence, while war, famine, and disease eliminate the human surplus. Ricardo, a prosperous broker, published in 1817 a penetrating analysis of the increasing use of poorer and poorer land under Malthusian tenets, suggesting that economic rent must continue to rise and the landowner benefit at the expense of both laborer and capitalist. With these elaborations the classical economics reached its high-water mark, though in the process it earned for itself the title of the "dismal science." There could certainly be nothing more cheerless than the prospect held out to the average man by the subsistence wage and the inevitable drudgery allotted to him by these *laissez-faire* speculations raised to the dignity of "laws" by false analogies drawn from the physical sciences. Instead of being part and parcel of the larger social unity envisaged by the Greek thinkers, economics now developed more and more an abstract and hypothetical existence of its own. Meanwhile the industrialist and landowner benefited, and the workers were left in want and misery.

At the same time that economics was being rescued from the mercantilistic demon to be thrown into the deep sea of *laissez-faire,* jurisprudence and ethics were suffering a similar fate at the hands of Jeremy Bentham (1748-1832) through his enunciation of the now-famous doctrine that the greatest happiness of the greatest number is the highest social and ethical ideal and that it can be best attained by allowing every one to seek his own interest and pleasure without restraint, since (and here is the catch!) the interest and happiness of each man coincides with the interest and happiness of all. Every thinking person now knows the

fallacy of this argument, but like *laissez-faire* it served its purpose in freeing the individual from certain medieval restraints, and thus it was another important step in the reëstablishment of freedom and democracy.

To seek the happiness of the greatest number is a laudable ideal, but it certainly cannot be achieved by each man's gratifying his own pleasure unrestrained by society. Yet this equivocal doctrine (latterly called utilitarianism) dominated the social thought of the first half of the last century, reaching its culmination in the writings of John Stuart Mill (1806-1873), who made it the touchstone of his politics, ethics, and economics. In the latter field, the classical doctrines of *laissez-faire* and free competition, which had become generally accepted, fitted admirably with utilitarianism, and in Mill's hands all these dogmas were interwoven. But Mill was more sympathetic toward human suffering than the economists who preceded him had been, with the result that he was led in his later years to favor a form of state intervention to protect the individual. This was directly opposed to the idea that inexorable natural laws govern economic affairs and that the government must keep its hands off. What Mill's later writings actually did was to give impetus to a revolt against *laissez-faire* which had already been gathering force and which assumed ominous proportions after the Second Reform Bill in 1867.

Soon after modern industry had developed out of the Mechanical Revolution, certain evils manifested themselves. Women and young children were forced to work incredibly long hours under unwholesome conditions and at starvation wages. Tremendous suffering and widespread unemployment became common. With the classical economists refusing to do anything about such matters on the strength of their dogmas, there developed a group of critics who denounced *laissez-faire*, declared themselves defenders of the

proletariat, condemned private property and the exploitation of laborers by capitalists, and demanded that the state take a hand by passing protective measures, controlling industry, and socializing various forms of property (another return to Greek ideas). The socialists, as they came to be called, were temporarily discredited with the failure of the French Revolution of 1848, but with the shift of their activity to Germany, a number of abler thinkers took up the theme.

Among these was Karl Marx (1818-1883), exiled from Germany to England because of his revolutionary ideas. Thoroughly imbued with Darwin's hypothesis of the struggle for existence and the survival of the fittest, Marx marshaled his facts, pictured an increasing struggle for survival between capital and labor, and predicted that when labor had secured the vote the inevitable outcome must be, so soon as capitalism had "ripened" and corporate enterprises had reached their maximum, that the people would take over the industries and run them. His "Das Kapital," published in 1867, created a furor, threw consternation into the ranks of the manufacturing class, and, along with other influences working toward the same end, resulted in numberless protective statutes to remedy the worst of the existing evils.

In Germany, England, France, and the United States, this flood of social legislation and the rise of trade-unionism (together with the apparent failure of some of Marx's predictions) seemed for a time to check socialistic progress, but the movement nevertheless advanced until to-day the parliaments of Europe have many socialistic representatives, socialist premiers have here and there been elected, a labor government in England has come and gone, and Russia (though not a manufacturing country and therefore not "ripe" enough according to Marxian tenets) has under-

taken an experiment in a modified form of socialism which has astonished and disturbed the rest of the world. Where the movement will end there is no predicting. Other radical forms of economic speculation (such as philosophic anarchism and syndicalism) have also taken shape, but it is beyond our scope to enter into them here. Marx's interpretation of social relations is unquestionably extreme and takes no account of certain important psychological factors which have since his time been more accurately appraised. His application of Darwinian ideas to economics was nevertheless important, especially his return to the Greek conception that economic society is not standing still but is developing through unconscious forces on the one hand and deliberate human effort on the other. The policy of government intervention to adjust differences between labor and capital has taken firm hold and has more and more superseded the classical dogmas.

§ 3

The change from inexorable *laissez-faire* to evolutionary conceptions in economics soon reflected itself in other fields of social activity. Governmental regulation and control, humane legislation, evolutionary ethics, sprang into existence; the conception of society as an organic unity came to the fore; and a new department of inquiry called sociology was born. This endeavored to encompass the entire field of human affairs.

The man who "predicted" sociology and gave it its name was Auguste Comte (1789-1857), a French social philosopher, who in a six-volume pre-Darwinian treatise, published from 1839 to 1842, endeavored to show that a science of society follows "inevitably" from the natural sciences. After the appearance of "The Origin of Species," the Comtian ideas were superseded by those of Herbert Spencer

(1820-1903), in whose voluminous writings, which extended from the middle of the century almost to its close, an attempt was made to apply the evolutionary hypothesis to society. Spencer gave to sociology its first consistent set of doctrines. Despite his genetic approach, however, and his repeated assertion that the new science must look to biology and psychology for its principles, his interpretation was almost wholly mechanical and deterministic, as was Comte's also. He talked in terms of an "equilibrium" of energy between society and its environment, of "natural forces" that operate in the social "organism" just as they do in the animal organism, of an "evolution" from militarism to industrialism, and of other "principles" which are quite ingenious but which have not met the test of historical research and social change. Furthermore, there was little or no psychology when Spencer was formulating his philosophy, so that his ideas have also been superseded as later discoveries pointed the way to better hypotheses.

Along with Comte and Spencer, Lester F. Ward (1841-1913) completes the triumvirate of founders of sociology. Ward emphasized what had previously been overlooked; namely, the preëminent importance of psychic factors in social progress. Ward's psychology was better than Spencer's, but it was still decidedly inadequate. He very naturally magnified the power of reason, though he seemed to appreciate that most of man's activity is instinctive and guided by deep-seated emotions which are usually quite unreasonable. He spoke of an original female sex which dominated early social development—as though one could talk of one sex antedating the other! He was, in short, governed in his thinking by misconceptions which even in his own day were being discarded. Yet he preached the possibility and necessity of improving society by conscious effort, and he was here pointing the way to a new point of view in modern

social theorizing, one that allows for the operation of man's volition in bringing about social change.

When everything is said and done, it must be conceded that sociology is still in the making. Its three founders gave it a name, some rough-and-ready theories, and an assortment of facts and fancies which are at present being sifted more thoroughly. Hundreds of sociologists are now at work observing, analyzing, and comparing social phenomena in many specialized fields. As Professor F. H. Hankins says in an interesting analysis contained in a recent book edited by Professor H. E. Barnes: "Sociology . . . is still a philosophy and a faith. . . . It has barely passed its formative stage. . . . As one leaves the founders and approaches the highly complicated but amorphous body of writings which constitute the literature of sociology to-day, he is rather bewildered by its luxuriance and variety and appalled by its mass. . . . There are many systems but little synthesis."

Nevertheless, although sociology is only in the formative stage, the large number of able specialists who are devoting themselves to it are laying its proper foundations. The following classification adapted from an inventory of the activities of some five hundred present-day sociologists by Professor Hankins in his analysis will serve to indicate the scope of their endeavors. Five major groupings are presented, under each of which there are a number of subdivisions indicative of the main interests of the specialists catalogued.

The first group embraces the astronomical, geological, and geographical sociologists, those whose interests lean toward the material factors in social organization. Among the specialties here listed are anthropogeography, topography and routes of travel, climate and weather, and food and natural resources. These represent important influences

which affect the development of society. About eleven per cent of the names catalogued fall into this class.

The second group brings together the biological sociologists, those who are making an exhaustive analysis of "the significance of vital principles and processes for social organization and evolution." Among the subdivisions here are the organismic school, who look upon society as an "organism"; the social Darwinists, who emphasize the struggle between races, nations, and other social classes as conditioning social evolution; the Malthusians, who stress "the relation of population to the means of subsistence, social prosperity, and cultural achievements"; the eugenists and the like, who point to "the selective rôle of organic traits and differential endowment in individual status and class stratification"; and the racial determinists, who emphasize "hereditary racial superiorities and inferiorities." About sixteen per cent of the names listed fall into the biological class.

The third group comprises the psychological sociologists, those who view society "as primarily a psychic phenomenon and process." In this class are those who emphasize particular "psychic traits and their social effects," such traits as reason, sympathy, suggestibility, imitativeness, and the like; others who stress instinctive behavior and the operation of such dominant impulses as hunger, sex, or combativeness; and still others who emphasize "the socialization of the individual through the moulding of inherent psychic traits . . . by the social heritage." About twenty per cent of the names listed fall into the psychological class.

The fourth group embraces the cultural sociologists, those who stress "institutions and cultural elements as self-originating and self-perpetuating phenomena." In this class are the economic determinists, the ethical and religious predestinarians, the anthropologists, ethnologists, and archæ-

ologists, and the cultural historians. This group comprises about seventeen per cent of the names listed.

The fifth group is a miscellaneous aggregation of "social philosophers, idealists, and reformers," among whom are included the rationalists, who stress the importance of reason, science, and education; and the anarchists, socialists, communists, syndicalists, Bolshevists, trade-unionists, single-taxers, philanthropists, criminologists, and others presenting a particular panacea of social betterment. About thirty-six per cent of the names listed fall into this group.

The rationalists (a most important subclass of the fifth group) boast of only half a dozen names out of about five hundred. These names, however, are significant—Lester F. Ward, H. G. Wells, Graham Wallas, James Harvey Robinson, John Dewey, and Walter Lippmann. We shall have occasion to see presently, in fact, that they comprise the vanguard of the scientific sociologists of the future, for they not only depend upon geology, biology, and psychology for their basic principles (as those of the first three groups rightly do) and upon history for their experimental laboratory (as do those of the fourth group), but, in addition, they insist that society is an artificial rather than a natural product, fashioned, partially destroyed, and reconstructed many times in the past by the wilfulness of man, and subject always to his deliberate design.

Despite the extensive investigations being undertaken in many specialized social fields, false analogies of natural law drawn from the physical and biological sciences still haunt the theorizing of most students of society; at least sixty-four per cent of the sociologists in Professor Hankins's classification are listed as determinists. (Most of the rest, furthermore, are catalogued as unscientific utopians.) Doubtless this deterministic classification is considerably exaggerated, but at all events it emphasizes a still prevalent

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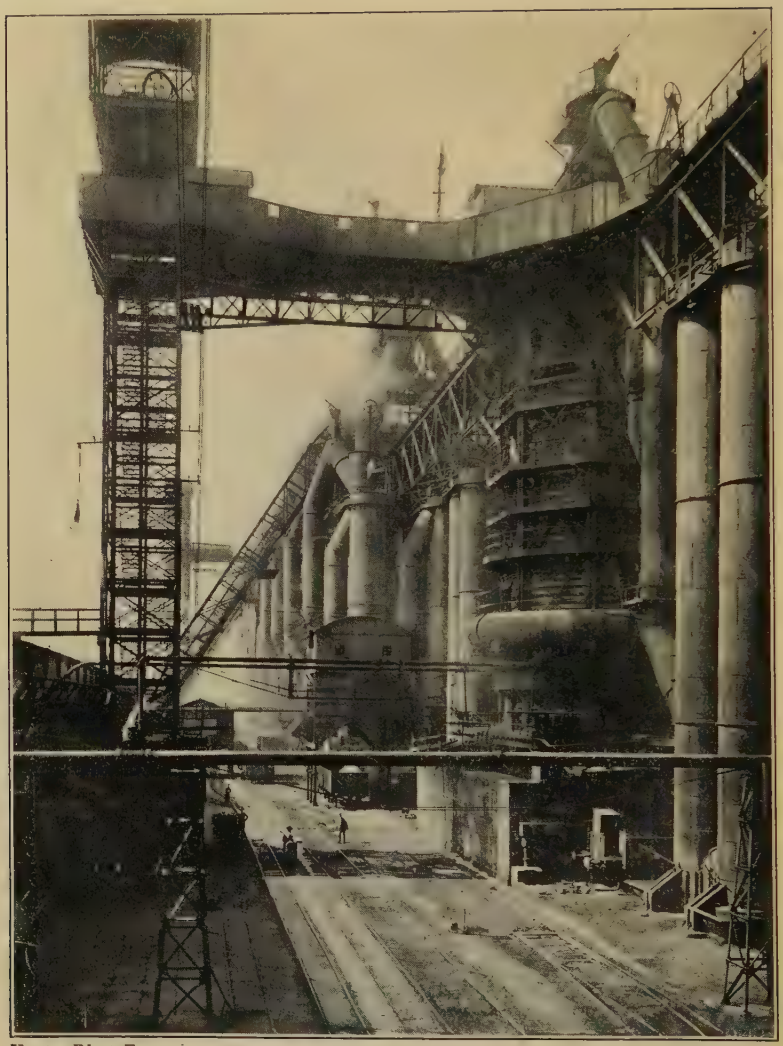

Krupp Blast Furnace

A MODERN STEEL MILL

(Like Society, an Artificial Creation)

tendency among sociologists which must be combated if the new discipline is to occupy a place of leadership among the other social studies, and if our social problems are to be approached in a hopeful spirit. In the meantime, however, the sociologists are building solidly with the natural sciences as their foundation.

At the same time that this new department of social study has been endeavoring to find a place for itself, its older sisters, economics, politics, jurisprudence, and ethics, have been converging more and more under genetic concepts and making ready to accept the leadership of sociology when it comes to maturity. Some of these, moreover, have been more successful in shaking loose the bogy of determinism.

Since the breakdown of classical economics and the rise of socialism, various so-called modern schools of economic thought have come to the fore, among which the nationalists, the historical group, and the institutionalists stand forth prominently. The nationalists are also called interventionists because they emphasize the close dependence between economics and government and maintain that state control of industrial activity is necessary for the greatest public welfare. This group insists that each nation should shape its economic policy to fit its own peculiar conditions. Free trade, for example, may be excellent for one country but ruinous for another. The historical economists follow the reasoning of the nationalists but go further and eschew all abstract theorizing, insisting that only in historical perspective can the development of industry be understood. Through observation, retrospective investigation, and inductive reasoning, they hope to build up a real science of economics. The institutionalists represent the most comprehensive effort to bring economics into line with the other social studies as part and parcel of an all-embracing science

of sociology. They make use of the historical, analytical, and statistical methods to arrive at a descriptive understanding of present and past economic institutions and emphasize the dependence of economics upon biology and psychology. In addition, it should be mentioned that many economists who are not institutionalists are becoming more and more interested—as are a number of prominent business men—in making first-hand observational studies of current economic and business conditions. Statistical research by the United States government, by business organizations, and by privately endowed institutions such as the Harvard Bureau of Business Research, has been developed on a considerable scale in recent years. There are many hopeful signs that economists and business men will soon know our industrial system in every important detail and that there will follow adequate measures to remedy some of its most flagrant shortcomings, from the standpoints both of business efficiency and human welfare.

In current political thought, historical and evolutionary concepts are also being stressed, and the "natural law" and "social compact" theories have been repudiated. Other eighteenth-century dogmas, however, are still holding fast, even though recent developments in international law and in the establishment of the League of Nations have considerably modified the publicist's ideas of state sovereignty and national supremacy. For four centuries the state has been the dominant political institution, church, gild, and trade-union occupying positions of subordinate governmental influence; but there are definite signs now that nationalism and state sovereignty have reached their apogee, and that other social forces—international, economic, juridical, and ethical—are coming into the ascendancy. Publicists here and there are giving prominence to these newer tendencies and are reëmphasizing the Platonic

and Aristotelian concepts that nations are man-made and can be remade in the light of more scientific political theories. The relation of politics to the rest of the social studies is being increasingly recognized, as is also its dependence upon biology and psychology.

On the side of analyzing modern governmental systems and practices more adequately, the same wholesome tendency of observational study is in evidence as was noted above with respect to economics. Extensive investigations by bureaus of research and similar organizations are being conducted into problems of municipal government, political parties, constitutional and administrative law, and other specialized governmental fields. The actual working of our present-day political machinery is being studied to excellent effect. Perhaps here, too, we will soon have caught up with Aristotle. In practical jurisprudence, under the leadership of such men as Roscoe Pound, we have apparently already surpassed the ancients, for in this field of social study there has been launched a series of investigations which not only encompass extensive codifications of existing law but are endeavoring to arrive at its social effects, its degrees of enforceability, and its relationship to morals, preventive justice, administration, and other related fields of social activity.

Current tendencies in legal theory are closely associated with developments in political thought, except that jurists have been discarding medieval misconceptions somewhat faster than have the publicists. With the opening of the twentieth century, jurisprudence had already passed beyond the historicogenetic stage of interpretation and had definitely entered the ethical and sociological phases of development. The attempts by jurists to formulate an ethical ideal for society have not yet proceeded very far, as is but natural with psychology still to some extent in the mak-

ing, but the important fact is that they now regard law as something consciously made by parliaments and courts and are endeavoring to set up a norm or ideal to guide its further formulation. The most advanced among them go even further. They look to past experience and custom, to the other social studies, and especially to mechanical, biological, and psychological forces for the basic facts out of which deliberate human effort may fashion the legal concepts of the scientific society of to-morrow. In this comprehensive approach, definitely throwing down the gantlet to social determinism, the sociological jurists join with the rationalistic sociologists (the half-dozen mentioned above) in pointing the way to constructive social advance.

But the ethical ideals for the guidance of this future social order are still to be completely formulated. Ethics has come to be so definitely associated with morals and religion that here the ancient Greeks are as yet ahead of most moderns in rational analysis, even though our basic biological and psychological facts are infinitely more adequate. The utilitarian standard of the greatest happiness for the greatest number has had an extensive vogue and is in itself, as already suggested, a laudable social ideal. It appeals to common sense and accords with modern biological and psychological findings. Men and lower animals alike strive for self-realization and the propagation of their kind. To live happily and to live more abundantly, either personally or in offspring and loved ones, is a desire that evidently permeates the whole of animal creation. So far, so good; but this broad gospel helps us little in setting up standards of conduct, for under it the lower animals have just as much right to live as we humans have, and, even after we restrict its scope to man, how distinguish between the desires of the despoiler and those of the saint? One man's self-realization and happiness may be and often are

destructive of another's. It is not true, as the hedonists and utilitarians have usually assumed, that the interests of the individual always coincide with those of the group. One may say that the *best* interests of both are identical, but this simply begs the whole question, and it is just here that so much confused moralizing has occurred. For how determine these best interests? Certainly not by leaving it to each individual to pursue his own selfish ways regardless of the rights of others.

Conflict of interests there always is, not only between individuals but also within each individual himself. The crucial ethical task for society is to act as an arbiter between conflicting human desires and to erect standards which will best advance both the individual and the group. The group is, of course, made up of individuals, so that the first step to a scientific social ethics is to determine what the fundamental human interests, instincts, motives, capacities, and desires are. These are questions for biology and psychology to pass upon. Hence the necessity of waiting for these natural sciences to have their proper say. Then it is a question of balancing and reconciling conflicting tendencies in the light of past experience as revealed by history and of determining upon a rational program for the achievement of the utilitarian ideal. This is not a simple matter, nor can it be encompassed by an elementary formula. It will necessitate the same painstaking research and marshaling of facts which any other great scientific generalization has required. And these facts ramify throughout the whole of present and past societies. All the social studies must be called upon for assistance in the establishment of the scientific ethical standards of the future. Possibly some public-spirited man or woman of wealth is even now contemplating the establishment of a Bureau of Comparative Morality or an Institute for the Formulation of Ethical Ideals!

Modern thought in the specialized fields of social study just reviewed is executing a return to Plato and Aristotle. It is coming to be realized once more (after a lapse of about two thousand years!) that politics, economics, jurisprudence, ethics, and all the other social fields are part and parcel of the same society, subject to change not only because of cosmic forces beyond human control but also through man's deliberate planning. The various fields of social activity lose their significance unless they are thought of as interrelated and interdependent at every turn. It is futile to expect to arrive at fundamentals in them until a well formulated set of sociological principles has been established.

Taking a bird's-eye view of the last two thousand years, what shall we say, then, of the social studies and of social progress? Regarding the social studies, we may answer that speculative theories have improved precisely as biology and psychology and the sciences upon which they are built have advanced. Though sociology has not yet found itself, it is being erected upon a substructure of scientific principles of which the Greeks knew little. With respect to social progress, we have observed that advances in natural science have had important indirect effects upon the social edifice. But beyond these indirect effects, some of them beneficial and others quite the contrary so far as social welfare is concerned, we are hardly further ahead to-day than were the Greek city-states in the days of their glory. On the social side, we have been engaged all these centuries in endeavoring to win back the individual freedom from despotic oppression and the opportunity for self-realization which went into eclipse when Greece was swallowed up in the Roman Empire and Rome was engulfed in the barbarian tide. Here and there we have completely reclaimed what had been lost. Elsewhere the removal of the encum-

brances is by no means complete. Everywhere we find deeply rooted social prejudices to which intelligent and ignorant people alike cling tenaciously simply because they are part of their traditions and for no other reason.

But natural science in these latter days has prepared the way for a rapid advance in social affairs, if only the intelligent layman, as well as the social specialist, will do his share in assimilating the new outlook on life that has been created. Man's conceptions of matter, energy, space, time, and human sensation are transformed with a modern understanding of sound, light, and atomic structure; his ideas of humanity's relation to the cosmos, with a modern comprehension of the motions and constitution of the solar system and the rest of the heavenly bodies; his notions regarding the earth's age and its development through geologic time, with a modern discernment of its behavior and composition; his prejudices along lines too numerous to catalogue here, with a modern knowledge of his own physical and mental make-up and his kinship with the rest of animal creation. The transformation of point of view herein implied has as yet affected but a small part of mankind, and the forces of darkness and ignorance are apparently intrenched as strongly as ever to hamper its spread. A proper world perspective is a first essential to constructive social advance. There can be little substantial progress in the solution of human problems until the majority of people have become imbued with the spirit of modern science.

As for contemporary specialists in various social fields, it would seem that, in the light of the pressing character of the present-day social problems outlined at the beginning of this chapter, they have for the most part been blithely fiddling while Rome burns. Like Francis Bacon's theologians, many of them have been endeavoring with fine-spun webs of outworn theories to ascertain the number of teeth

in the mouth of the social horse. Yet there are happily some who have caught the vision of how social progress is to be achieved. To them we must look for the yeast which will leaven social misconception into scientific sociology.

§ 4

A few remaining considerations, to epitomize the most essential points developed in the preceding pages, will serve to bring our survey to a close. Four pertinent propositions bear emphasis.

First, the road to social progress looms clear and straight if advantage be taken of two sign-posts that point the way. One shows that society is not a natural but an artificial creation and that it has been constructed and can be reconstructed by human effort. The other declares that, to be scientific and well ordered, society must be built upon the natural sciences, and especially upon geology, biology, and psychology.

There has been and still is much half-baked talk about "natural laws" which work inexorably in the fashioning of society and which can be understood by a reading of history. Now a proper study of history is important for social advance, as has already been indicated, for thus are disclosed the conditions under which various experiments have been made in the past and their results. History furnishes a laboratory for the social studies; but it provides no method for separating the good from the bad in past experimentation. For this we must look to our second sign-post. As for anything "inexorable" in the shaping of society, the only constant factor thus far disclosed by history seems to be the interminable blundering of man. If there is one thing more than another which is clear to any one with even half an eye undimmed by prejudice or the specter of fatalism, it is that at every turn of events human caprice and wilful-

ness—whether guided by scientific insight, superstitious fantasy, self-aggrandizement, or just plain cussedness—have brought about changes in the social structure.

Sociology is not and can never be a natural science. It pertains to conditions that are man-made, and what man has made he can obviously change. Herein lies the essential difference between the Book of Nature and the Book of Society. The one can be revised; the other cannot be. The best we can do with Nature's Book is to unseal and study its contents. We cannot change the laws disclosed in it. We can only utilize them; but that is enough. On the other hand, the "laws" written in Man's Book are not unchangeable. History shows us clearly that they have been revised, in part obliterated, and added to many times in the past.

Society is an artificial creation just as the automobile or the steel mill is. Modern gasoline engines or smelting devices differ from their prototypes of half a century ago, and these from still earlier forms, because of the application of discoveries in physics and chemistry. Similarly, to elaborate upon the significance of our second sign-post, the social structure was bound to be primitive and unscientific until the necessary geological, biological, and psychological laws had been disclosed. It is subject to improvement just as conveyances and smelting devices are, once certain basic principles are applied with rational intent. Since geology, biology, and psychology have reached maturity only recently or are in part only now coming of age, it has not been possible until the present day to make rapid headway in the scientific fashioning of society. It is here that we must look for the cause of the stagnation of social progress thus far, as compared with the rapidity of material progress. It is in this respect that we are better prepared for social advance than the Greeks were. The necessary laws for the scientific reconstruction of society are now at our disposal.

They were not at theirs. Humanity is finally ready to undertake a thoroughgoing revision of the Book of Society in the light of the findings of the Book of Nature.

Somewhere in this thought lies the element of truth in the fumings of the fatalists and determinists. Man must follow the laws of nature if he would fashion an enduring social structure, but there is nothing to compel him to do this except his own intelligence and common sense deliberately employed. Up to the present time he has exercised these superior faculties in the social sphere only too infrequently. From now on, if he will be guided by the two signposts to social progress, he can hardly be led astray.

Secondly, to construct a scientific society man must, as another preliminary, know the preceding societies his forebears have built, which involves a study of history; must understand the society that exists at present, which comprehends what the inductive sociologist, publicist, economist, and jurist are laboring to accomplish; and must formulate an ethical ideal around which his improved society can develop. History has not always been the chaste handmaid of unbiased chronicle which she is now becoming through the efforts of a few synthetic historians. She has too long been the charwoman of political expediency. Yet a clear understanding of how man has lived in the past is essential to a betterment in the organization of society, so as to avoid a repetition of the mistakes that have already occurred and to improve on constructive achievements which have nevertheless fallen somewhat short of being completely satisfactory. It stands to reason, also, that an unbiased observational understanding of present conditions, a picture in which nothing is hidden from man's view, is likewise of importance.

Still, all the knowledge in the world of past and present social conditions will not give us any inkling of the *direction*

of social progress. For this we need appropriate ethical standards, based on scientific principles and echoing humanity's deepest desires. These are still to be formulated, though our second sign-post clearly points the way for students of ethics to take.

Thirdly, the realization that it has taken two thousand years to regain the position in social affairs which the ancient Greeks had once attained must come as a shock to all of us. If social progress in the future were to be measured in terms of past achievement, the outlook would be dark indeed, for in a single generation—the time span of most interest to those living—very little could be accomplished in the solution of the social problems which seem daily to become more insistent. But fortunately there is a better way than the muddling of the past twenty centuries, a way for which we are now ready, the way of science. What physical science has accomplished in one brief century, and is continuing to accomplish with ever increasing impetus, has been indicated. There is every reason to believe that geological, biological, and psychological "revolutions" are to follow in the wake of the changes wrought by physics and chemistry, and that the social structure will be markedly affected in the process. Yet this is not all. The influence of natural science upon the social structure has thus far been incidental and indirect. There has been no real science of sociology to go by. Once this is properly organized and sufficiently established we may expect as rapid progress in the social field as the nineteenth century witnessed in the material realm.

Fourthly, there is no occasion to become panicky over the scientific refashioning of society. It does not mean, as some radical propagandists are fond of declaring, that existing societies must be destroyed before a healthier variety can come. Such a conception is no better than the

special creation hypothesis, for it sets man off completely from the rest of the animal world and assumes that his blind gropings and instinctive adaptations to environment have always functioned to his detriment, not to mention the fact that he has already utilized the findings of science to some extent in social change. Man's instincts, if not as automatic in their operation as are those of the ants and the bees and the birds, are at least made of the same stuff and have guided him somewhat in the making of his hills and his hives and his nests. Man's reason is also a natural product. Despite the fact that there is still much for it to do in human society, it has already guided man to heights of accomplishment where mere animal instinct lay impotent. Practically all the rest of animal creation, outside of a few remaining ultra-microbes, are already at man's feet. His reason has put them there. It is senseless to assume that man's groping efforts to build a social habitation for himself have all been futile. It is a question of *improving* upon what he has already accomplished, not one of destruction.

It is not that man has made no social progress throughout the ages. He has gone faster and further than any lower animal. It is simply that he has recently gone infinitely faster in the mastering of nature's resources and that, by contrast with this greater human accomplishment, his social achievements shrink into insignificance. But he has heretofore not been ready for rapid social advance. He has had to penetrate nature's secrets first. For more than two thousand years he has been occupied in this preliminary task: first, in ancient Greece, finding the way of science and breaking the first seal which shut the Book of Nature from his understanding; then losing the vision for a long period, catching it anew in the sixteenth and early seventeenth centuries, when he broke the second seal, and following this achievement soon afterward with the shattering of the

third; another hundred years pass before the fourth seal gives way at the beginning of the nineteenth century, which, before its close, is to witness also the breaking of the fifth and sixth. Inasmuch as the seventh seal has not yet been completely shattered, one might hold that man is even now not ready for the greatest of his tasks, the building of a better social order. Still, much has already been disclosed with the breaking of the first six seals, which man has hardly begun to utilize. Man did not appreciate until very recently that his Book must harmonize with Nature's Book if an enduring social structure is to be forthcoming. He had not realized that in natural science lies a guide infinitely better than his instinctive social fumblings. Now, with Nature's Book almost entirely open before him, destiny bids him read and assimilate and apply the results with deliberateness to human affairs.

To achieve this end, in conclusion, we should remember that it is not only through observation and experiment but also through speculative hypothesis that scientific progress has come. The two extreme schools of thought, represented by Aristotle and Plato among the ancients and by Bacon and Descartes in the scientific renaissance, are still with us. One group of thinkers has its nose close to the grindstone of facts and scoffs at all such attempts to explain obvious mysteries as vitalism, telepathy, or spiritism. Intoxicated by the achievements of physical science, it sees mechanism, materialism, and determinism everywhere. On the other hand are those who continue to evolve "solutions" to social problems "out of their inner consciousness" regardless of scientific fact. The social fields are encumbered with "specialists" who do little more than spin endless webs of ever more tenuous theories out of what some one else has dogmatically stated. Both types of extremists paw the treadmill of the past, one group satisfied with what facts

have already been adduced, the other missing the facts completely but enamoured of the written word.

It behooves us to steer a middle course between these extremes, neither failing to keep our feet firm upon the ground of indisputable fact nor fearing to raise our heads aloft into the free air of speculative hypothesis. There are innumerable questions of vital import before which science as yet stands helpless. It may never be able to provide satisfactory answers to all our problems. Shall we give up our beliefs and theories about them because some physical scientist, perhaps eminent in his particular field, sees everything in terms of his own narrow hobby? He also has plenty of beliefs, even in the very specialty he endeavors to make the measuring-rod of all the mysteries that lie outside. The only intellectual crime we can commit in this connection is to hold our beliefs so dear that we refuse to change them in the face of contrary fact. With a free and forward-looking point of view and an understanding of what science has already achieved, humanity stands ready to move consistently forward along the road of social progress.

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